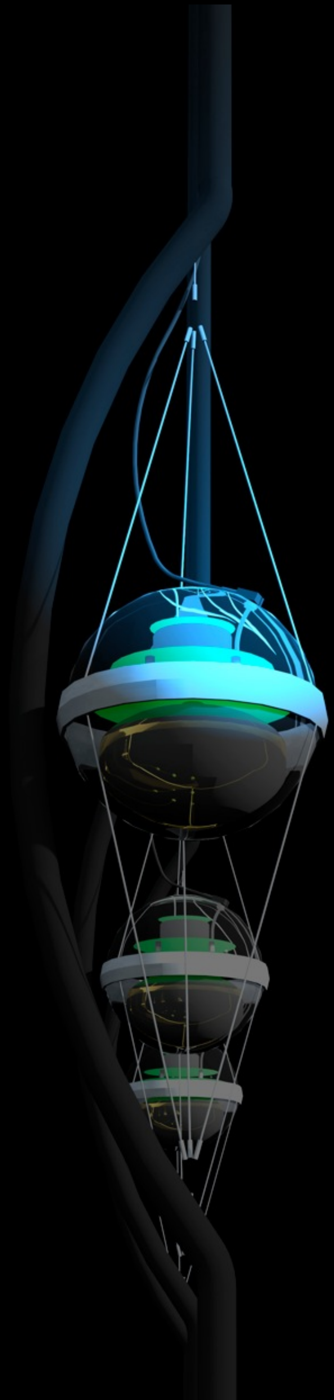
cosmic neutrinos and multimessenger astronomy?
francis halzen



- we have observed a flux of neutrinos from extragalactic sources by multiple methods

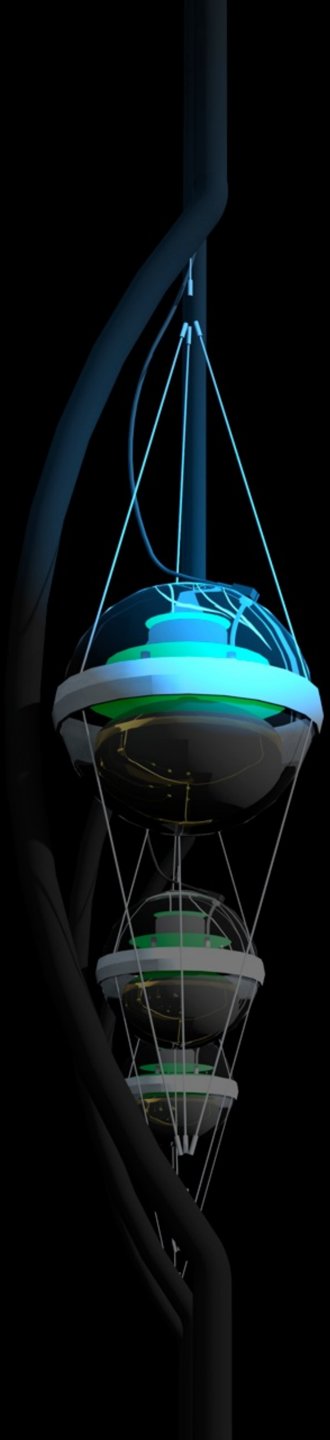
- their energy density in the universe is similar to that of the highest energy photons (and cosmic rays).

- cosmic neutrinos are accompanied by photons of similar energy

- after cascading in the source and in the EBL the photons may be observed below Fermi threshold (obscured sources)

- one example: a burst of 13 neutrinos in 3 months from the gamma ray source TXS 0506+056

icecube.wisc.edu



- cosmic neutrinos: four independent observations
  → muon neutrinos through the Earth
  → starting neutrinos: all flavors
  → high energy tau neutrinos
  → a Glashow resonance event

- IceCube neutrinos and Fermi photons

- the cosmic ray accelerator TXS 0506+056

- multimessenger astronomy from radio to PeV neutrinos

- a new class of sources?

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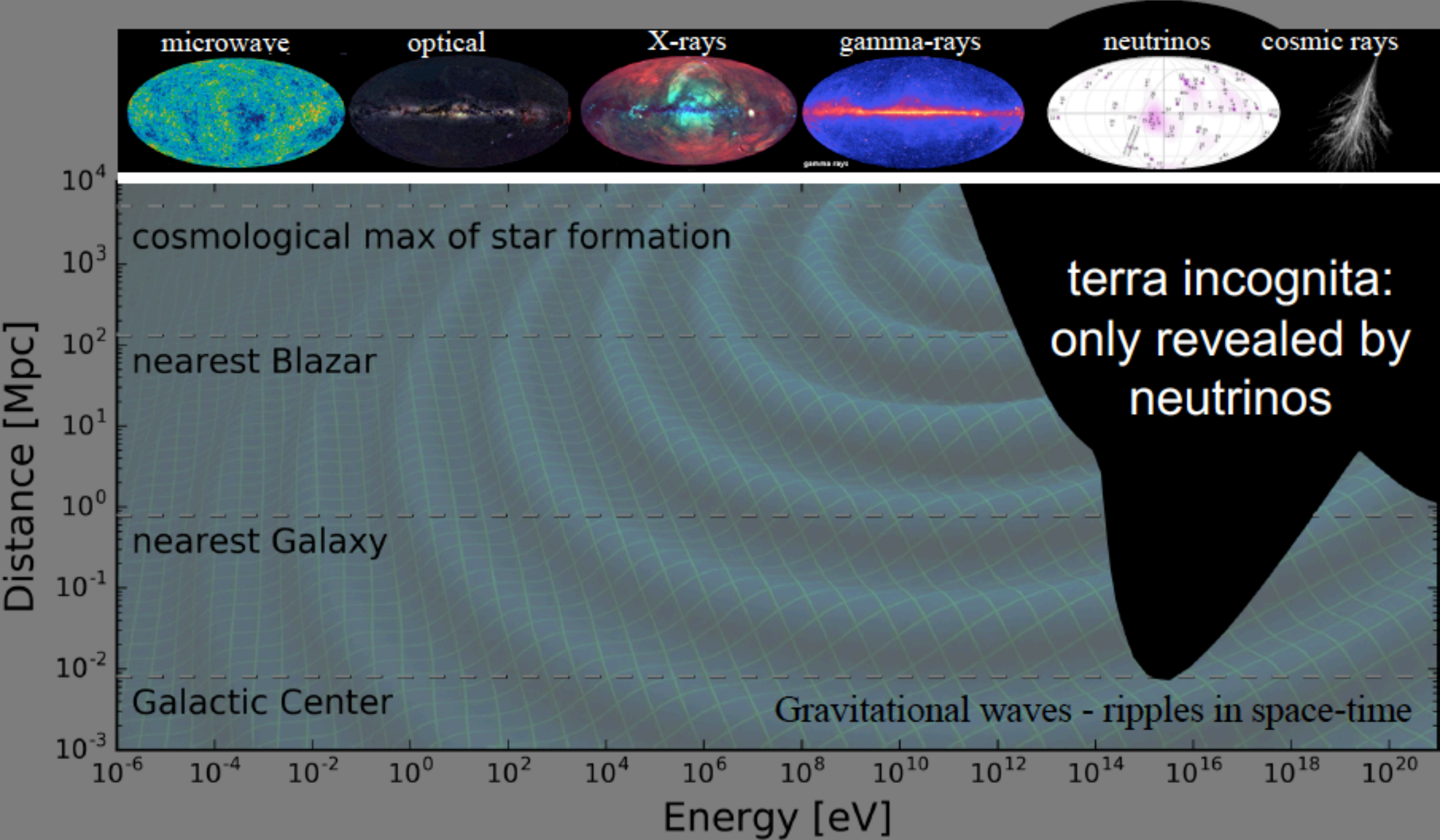
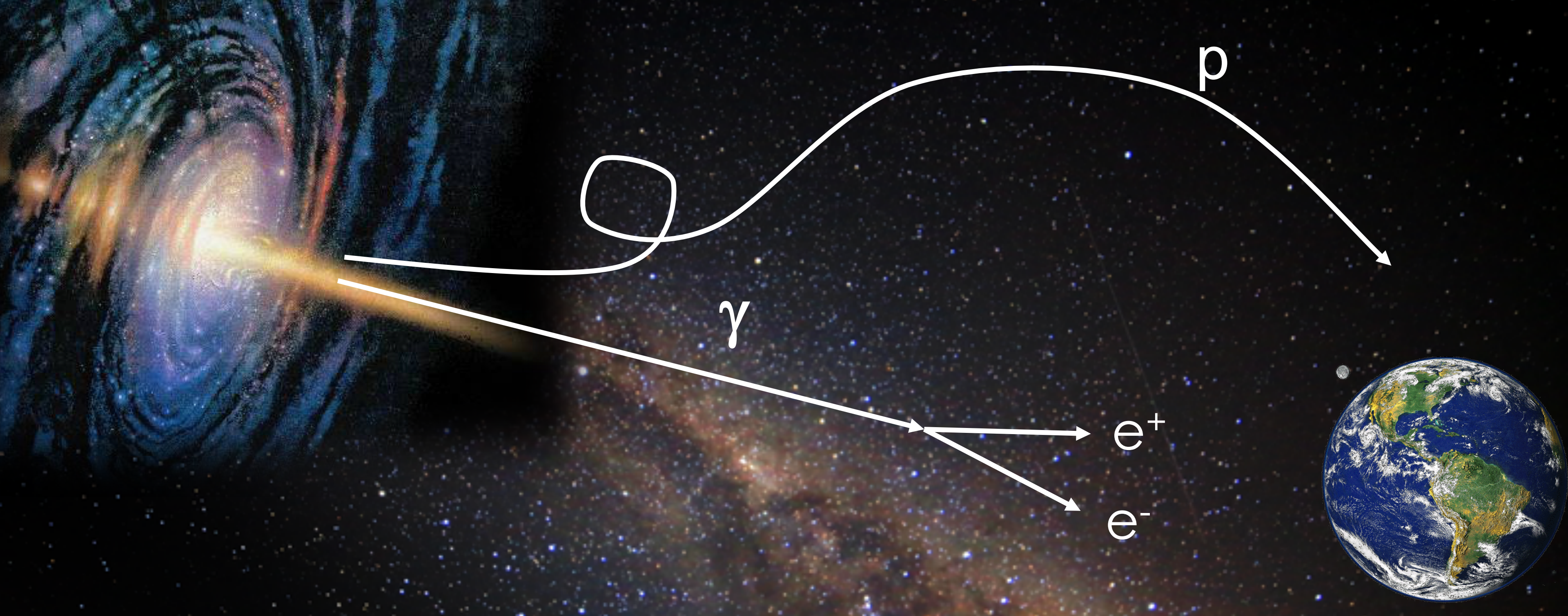


- 20% of the Universe is opaque to the EM spectrum
- non-thermal Universe powered by cosmic accelerators
- probed by gravity waves, neutrinos and cosmic rays

The opaque Universe

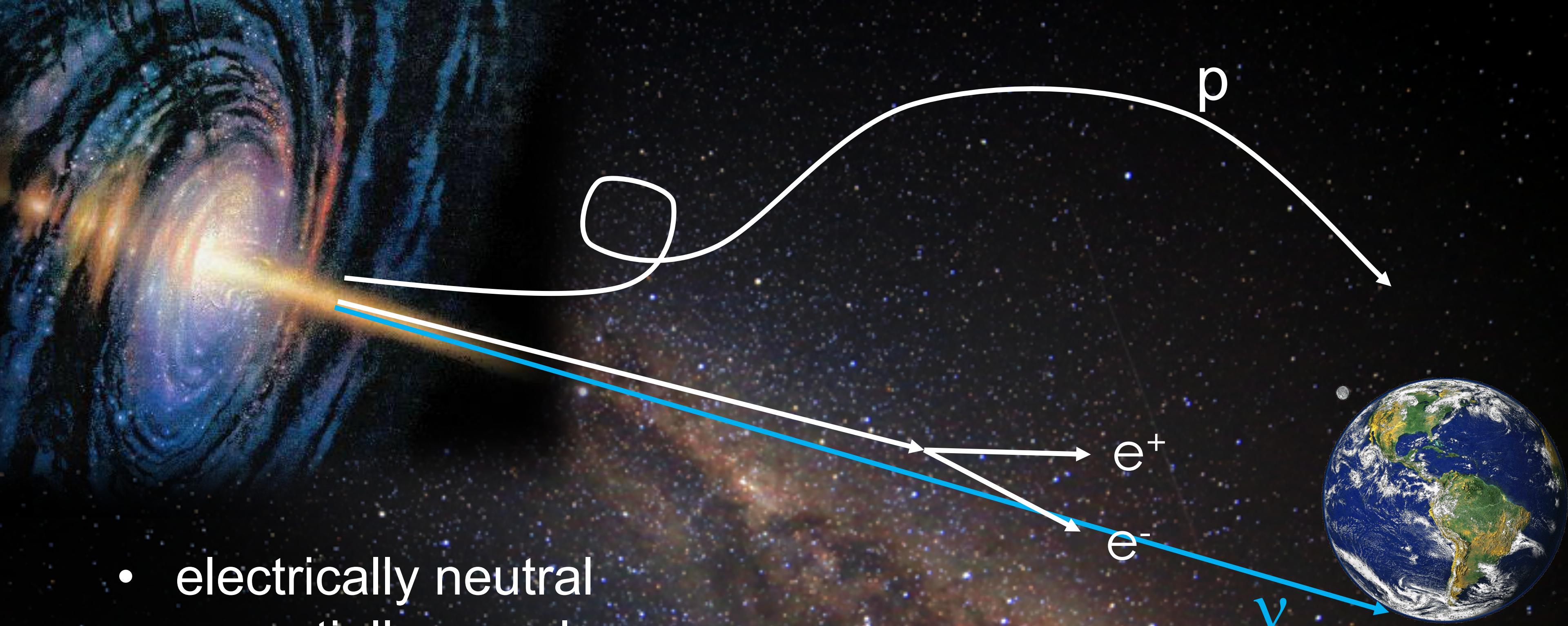


$$\gamma + \gamma_{CMB} \rightarrow e^{+} + e^{-}$$

PeV photons interact with microwave photons ($411/cm^3$) before reaching our telescopes

enter: neutrinos

Neutrinos? Perfect Messenger



- electrically neutral
- essentially massless
- essentially unabsorbed
- tracks nuclear processes
- reveal the sources of cosmic rays

- … but difficult to detect: how large a detector?

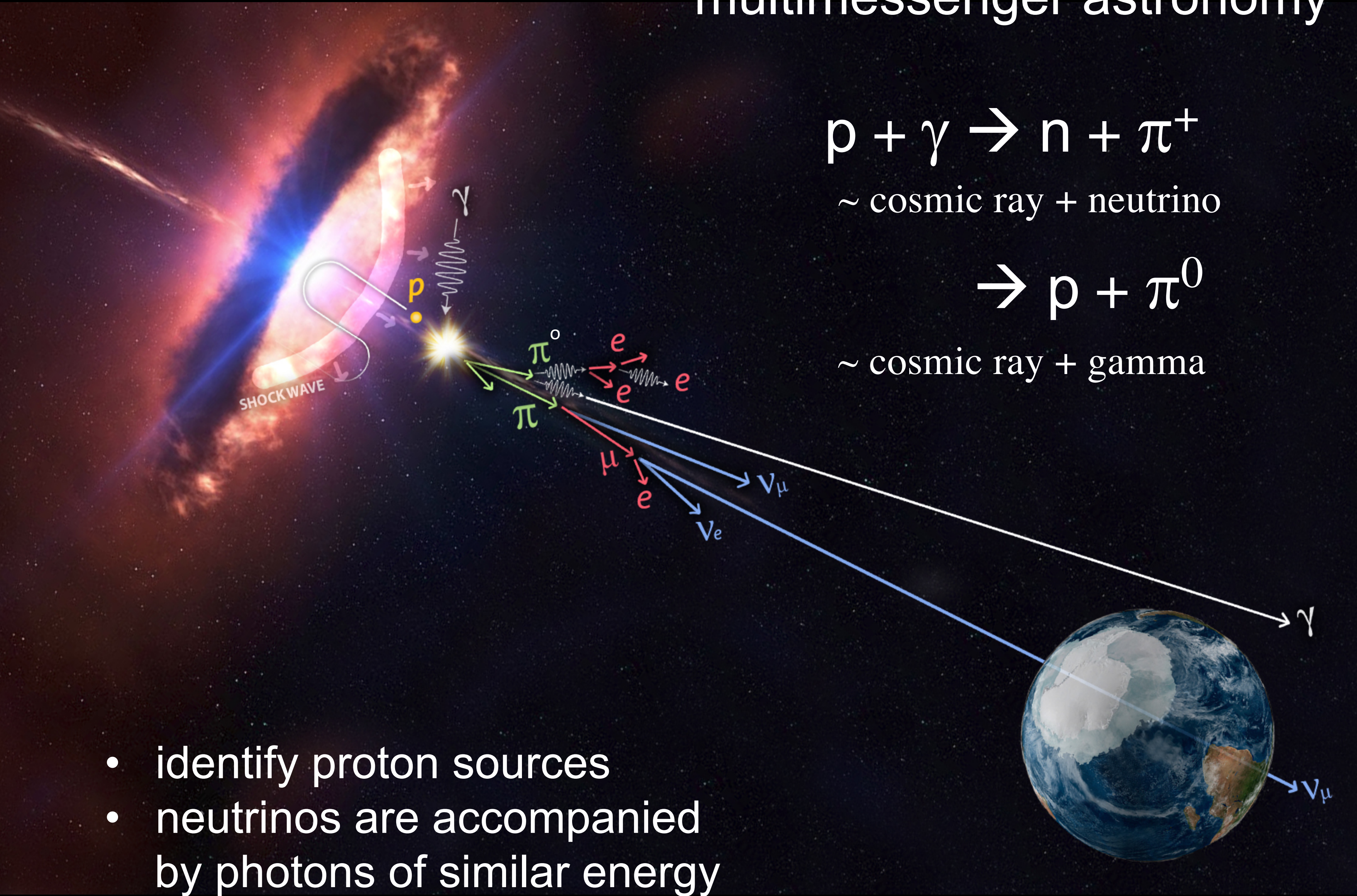
multimessenger astronomy

$$p + \gamma \rightarrow n + \pi^+$$

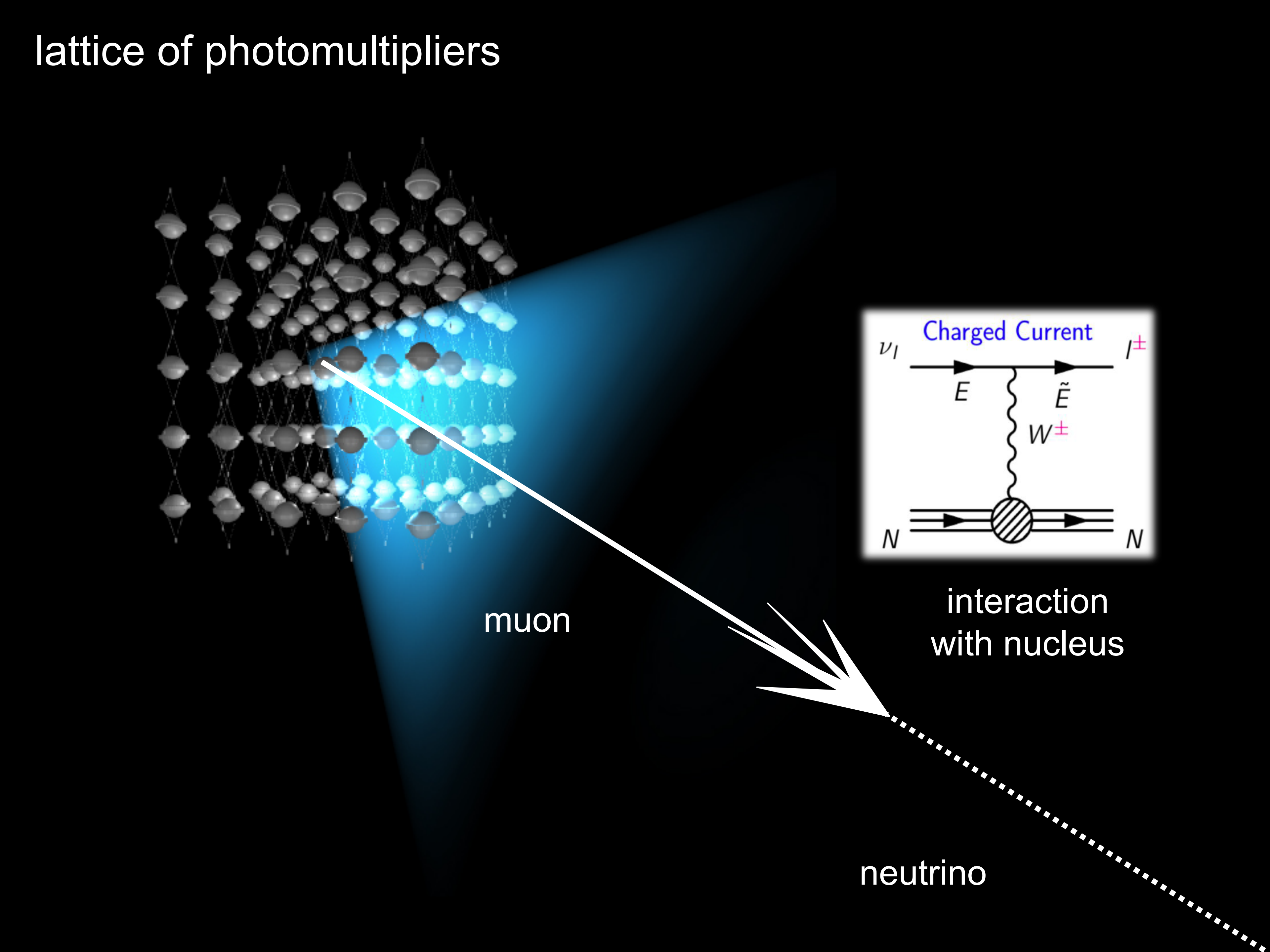
~ cosmic ray + neutrino

$$\rightarrow p + \pi^0$$

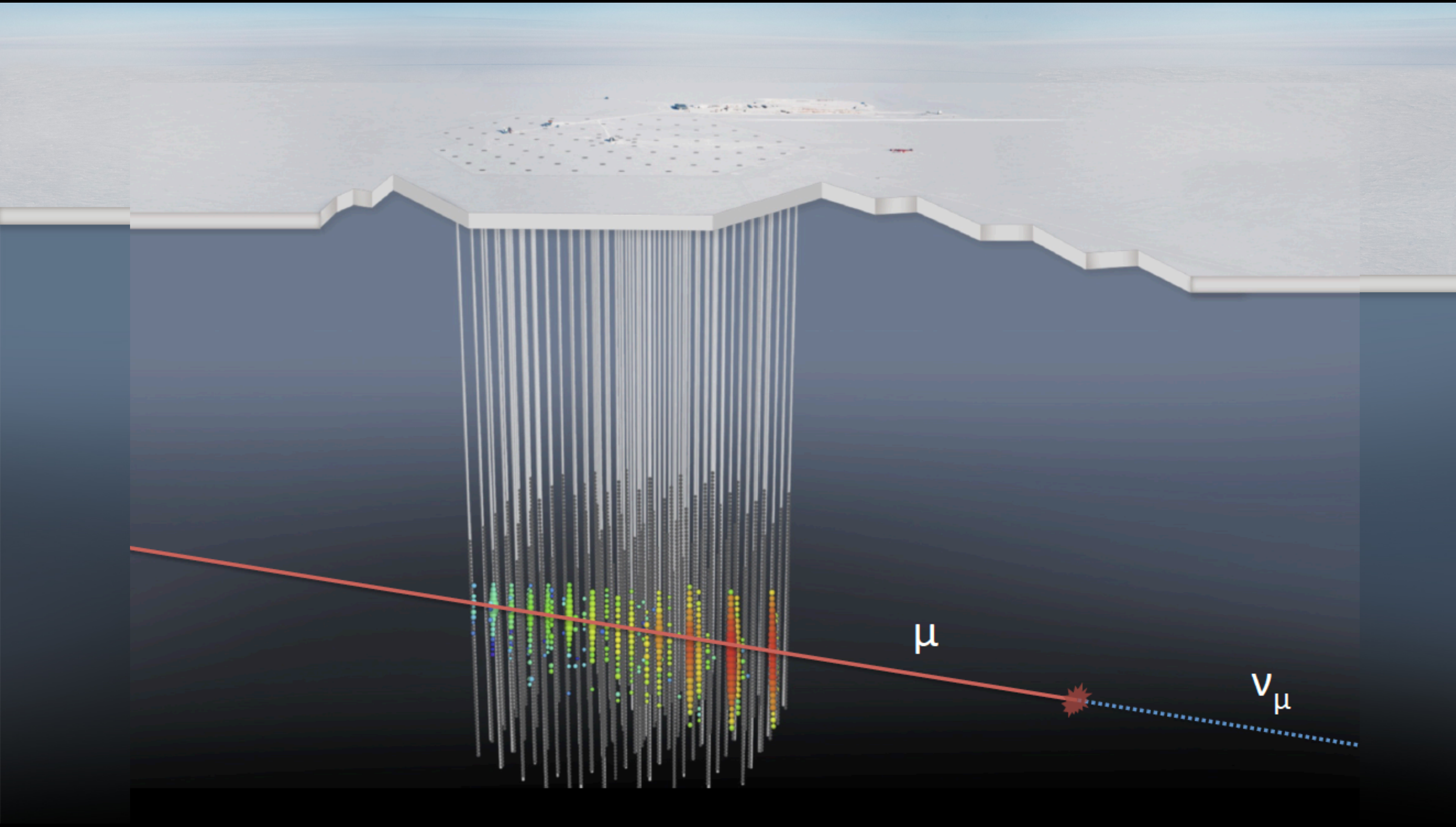
~ cosmic ray + gamma



- identify proton sources
- neutrinos are accompanied by photons of similar energy

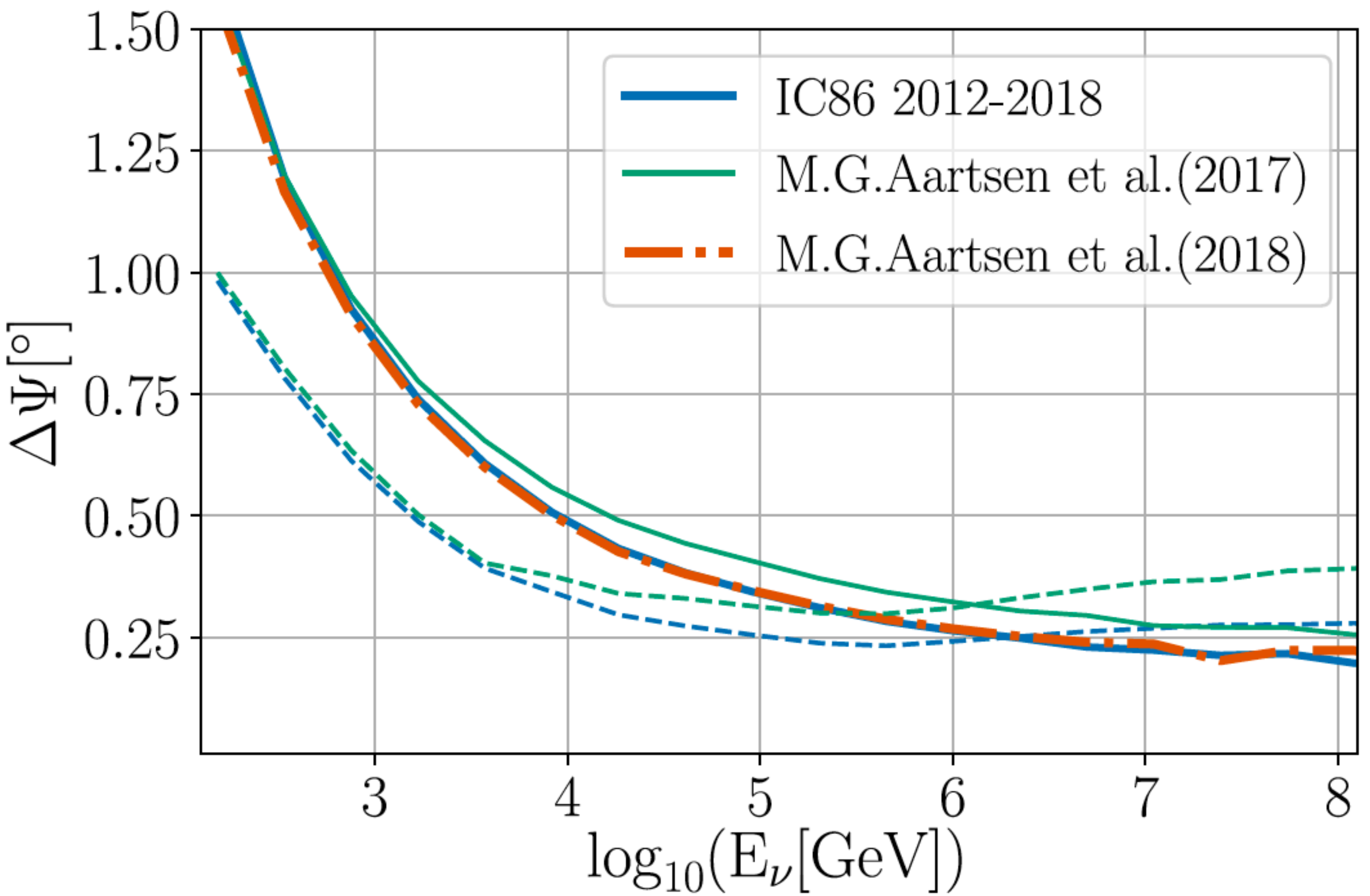

lattice of photomultipliers
Charged Current
ν_l
$l^\pm$
E
$\tilde{E}$
$W^\pm$
N
N
interaction
with nucleus
muon
neutrino

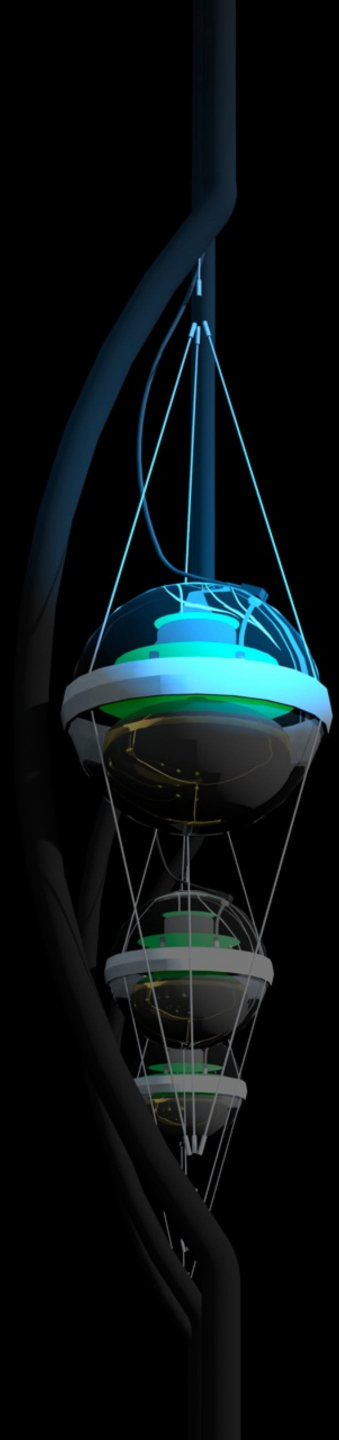
instrument 1 cubic kilometer of natural ice below 1.45 km



astronomy:

- through-going muons with resolution 0.2~0.4^0
- goal 0.1^0





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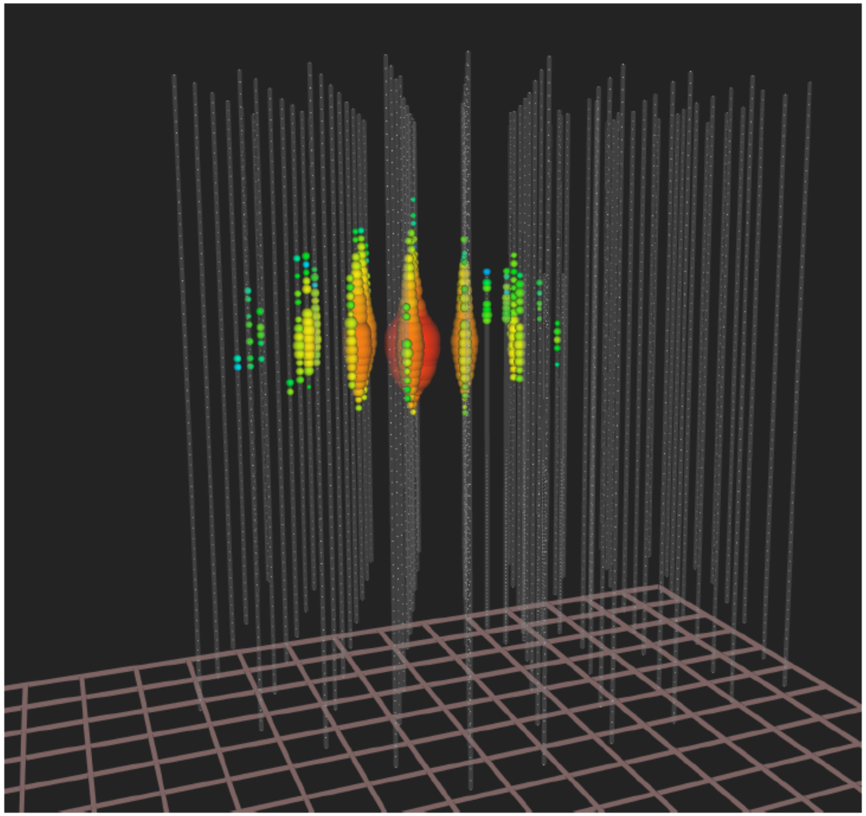
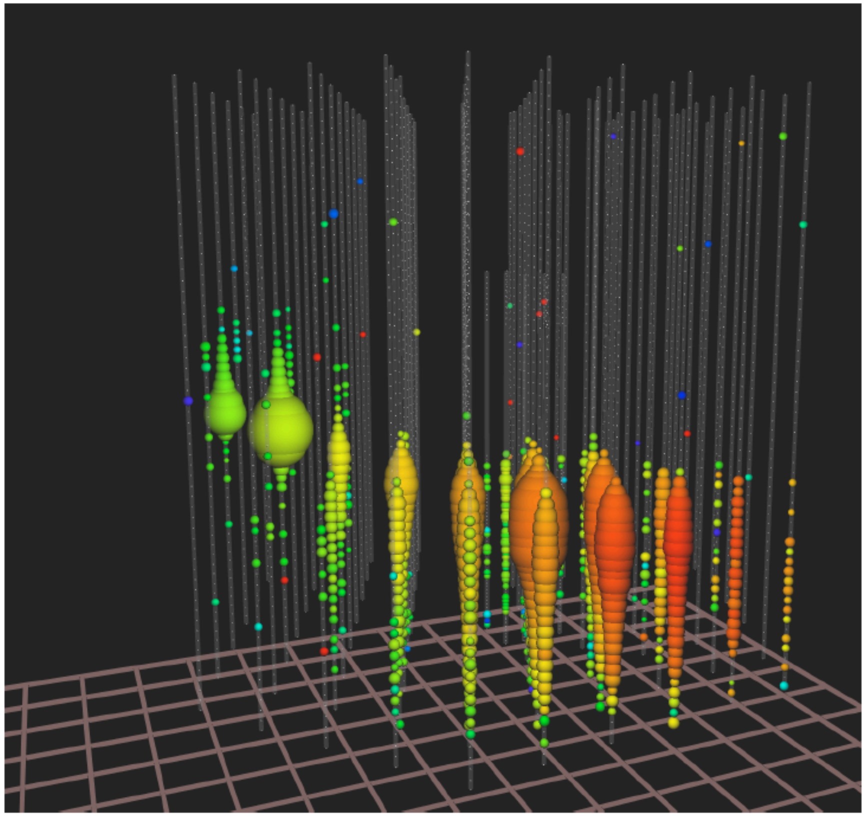
neutrinos interacting
inside the detector

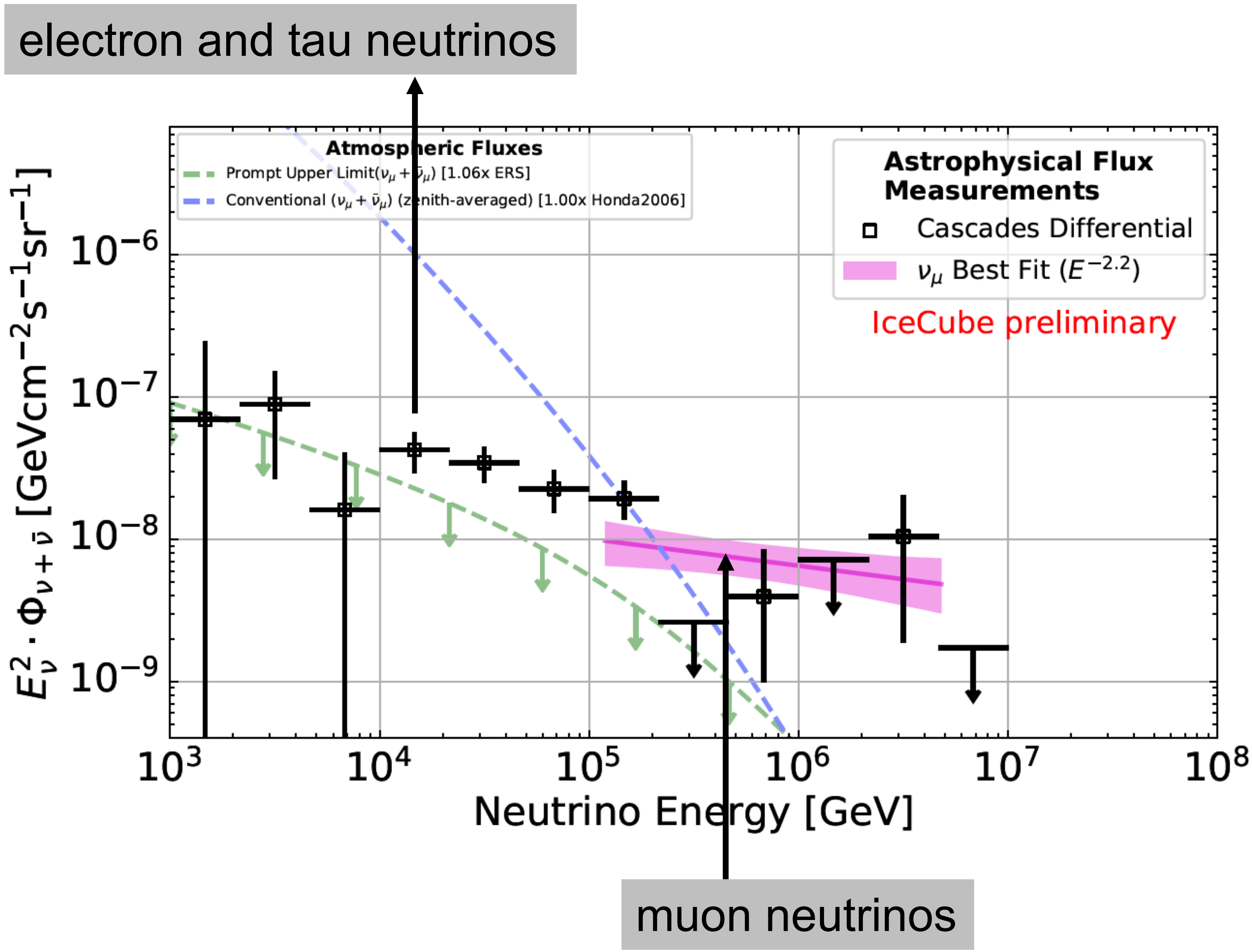
muon neutrinos
filtered by the Earth





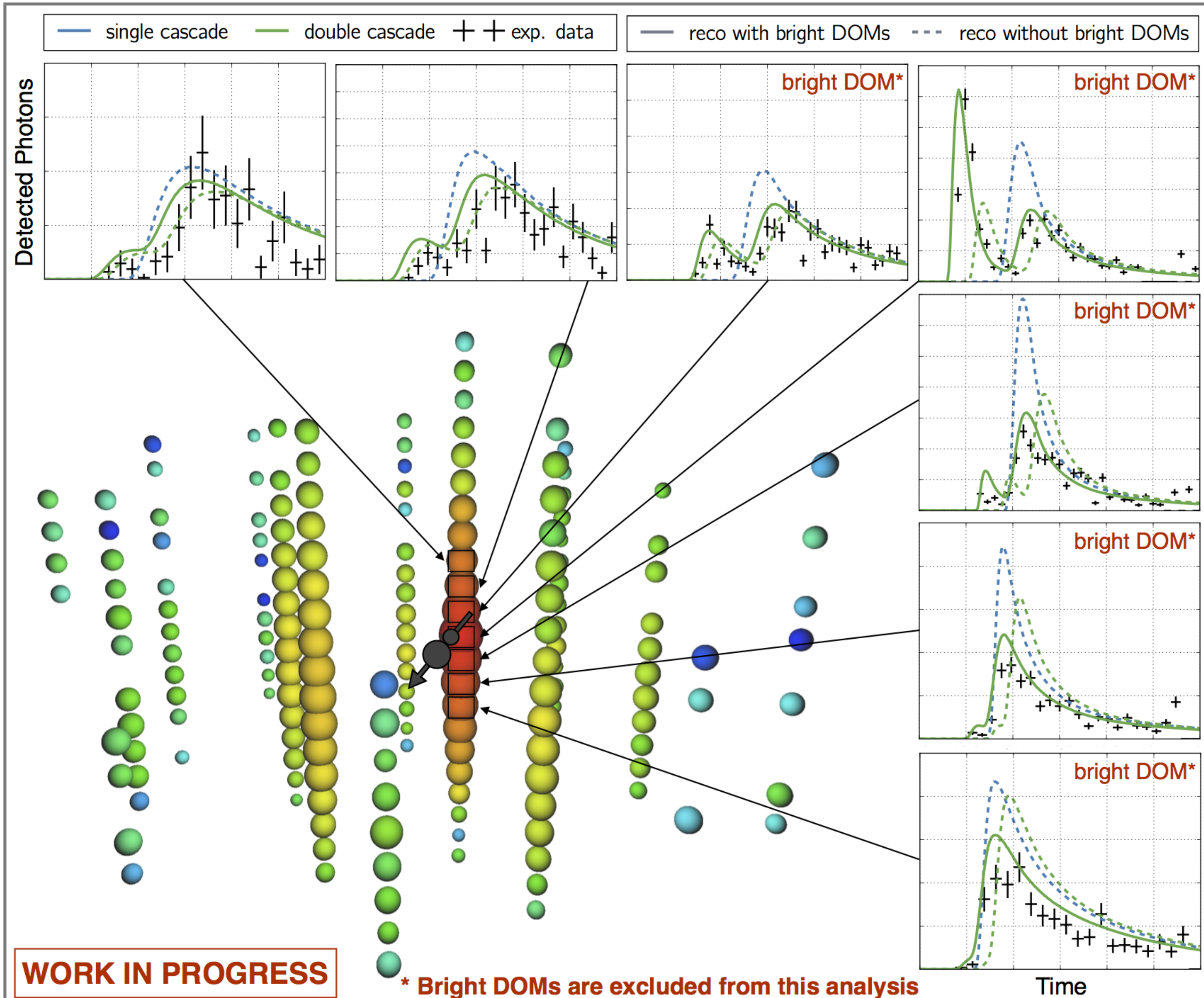
total energy measurement
all flavors, all sky

astronomy: angular resolution
superior (<0.4°)

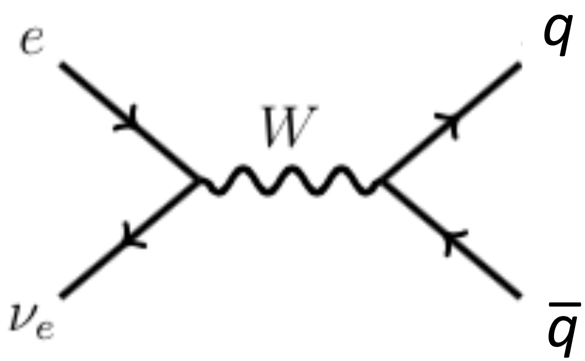


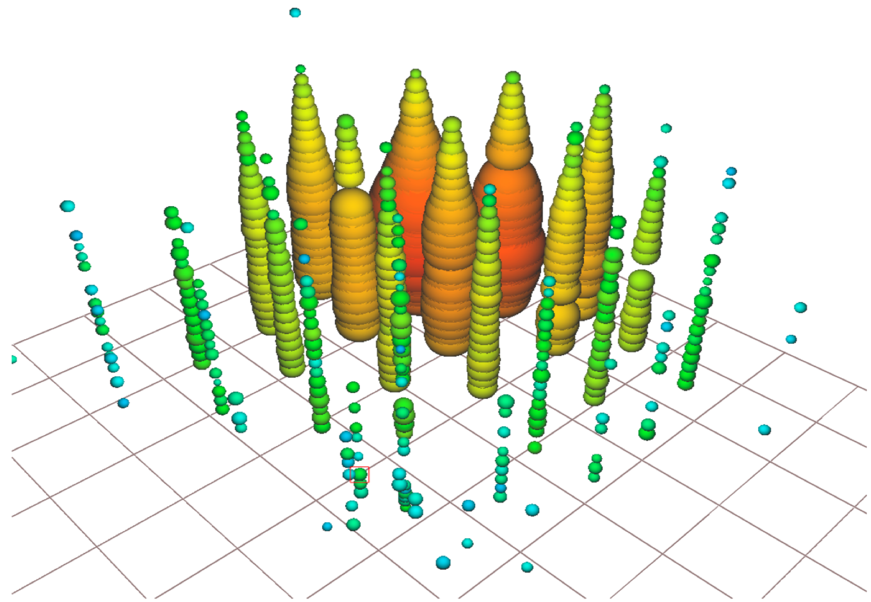
electron and tau neutrinos
Atmospheric Fluxes
Prompt Upper Limit($\nu_\mu + \bar{\nu}_\mu$) [1.06x ERS]
Conventional ($\nu_\mu + \bar{\nu}_\mu$) (zenith-averaged) [1.00x Honda2006]
Astrophysical Flux Measurements
Cascades Differential
ν_μ Best Fit ($E^{-2.2}$)
IceCube preliminary
$E_\nu^2 \cdot \Phi_{\nu+\bar{\nu}}$ [GeVcm^{-2}s^{-1}sr^{-1}]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^3
10^4
10^5
10^6
10^7
10^8
Neutrino Energy [GeV]
muon neutrinos

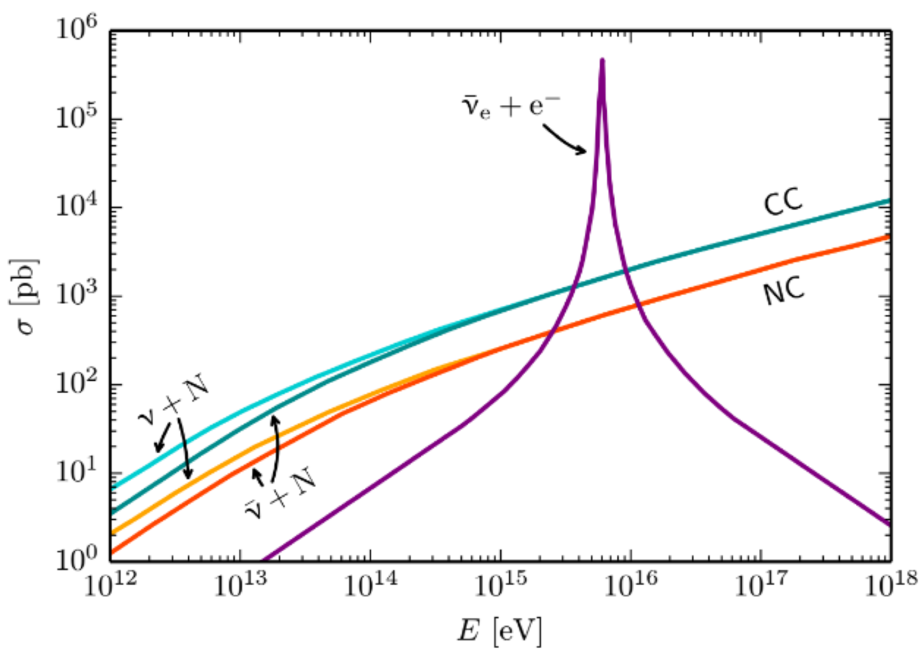
a cosmic tau neutrino: livetime 17m



Glashow resonance: anti-ν_e + atomic electron → real W





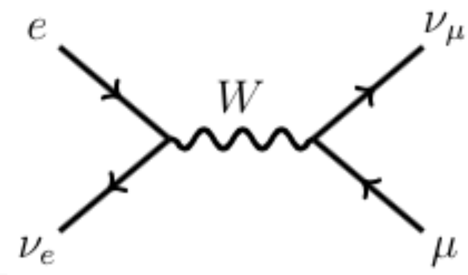


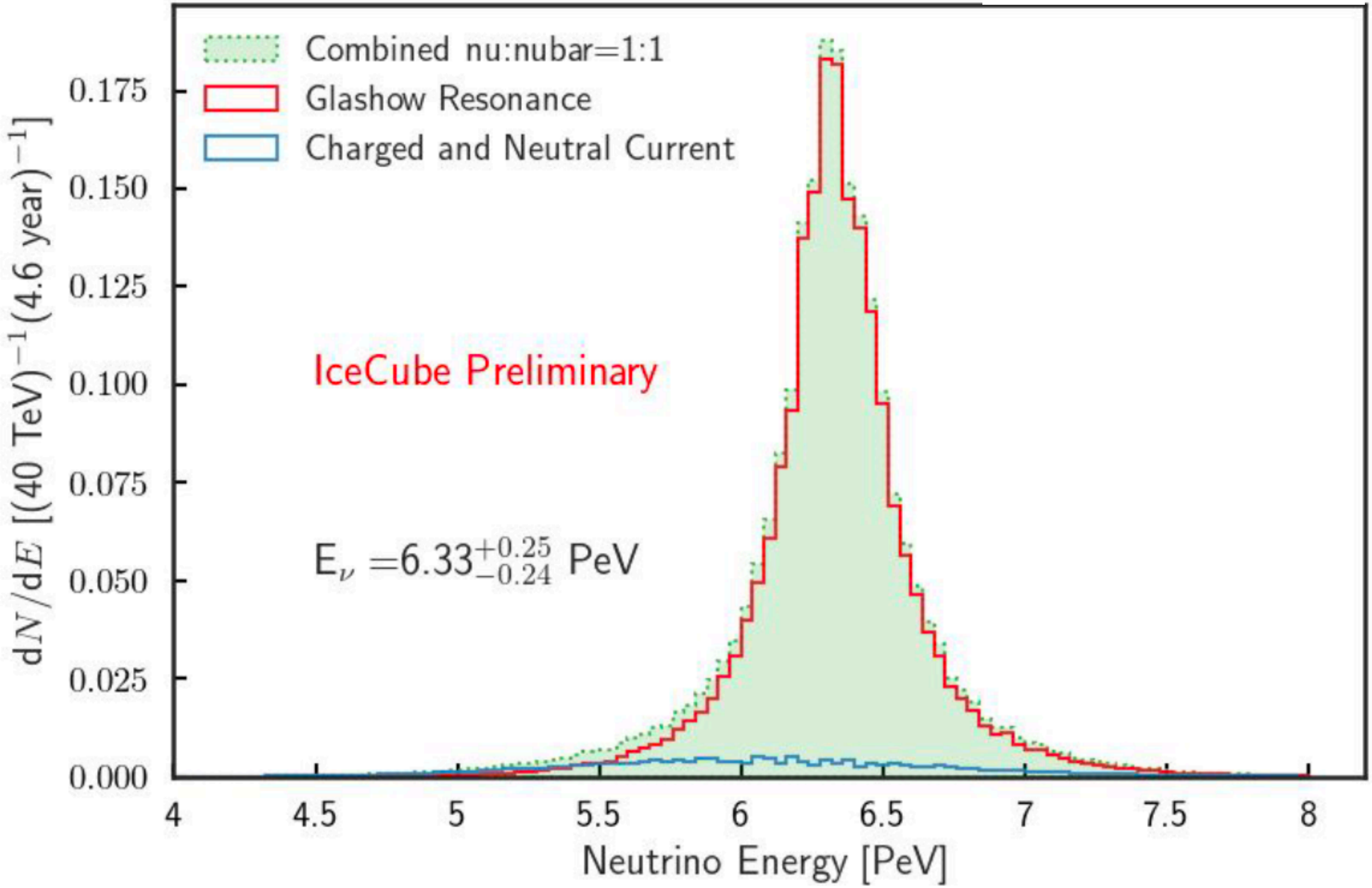
- partially-contained PeV search
- deposited energy: 5.9±0.18 PeV
- visible energy is 93%

- → resonance: E_ν = 6.3 PeV

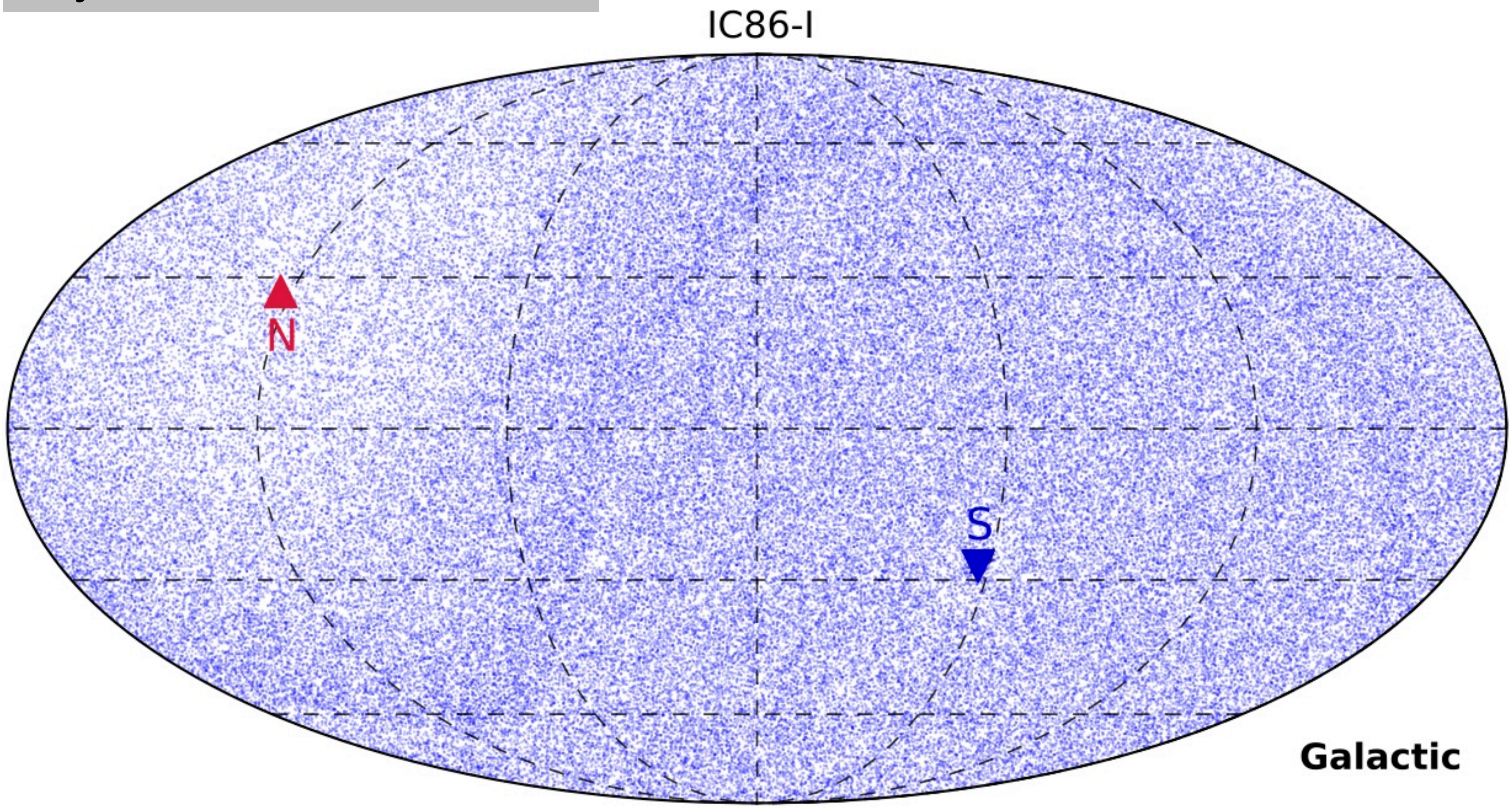
work on-going

- energy measurement understood
- identification of anti-electron neutrinos





1 year of IceCube data:



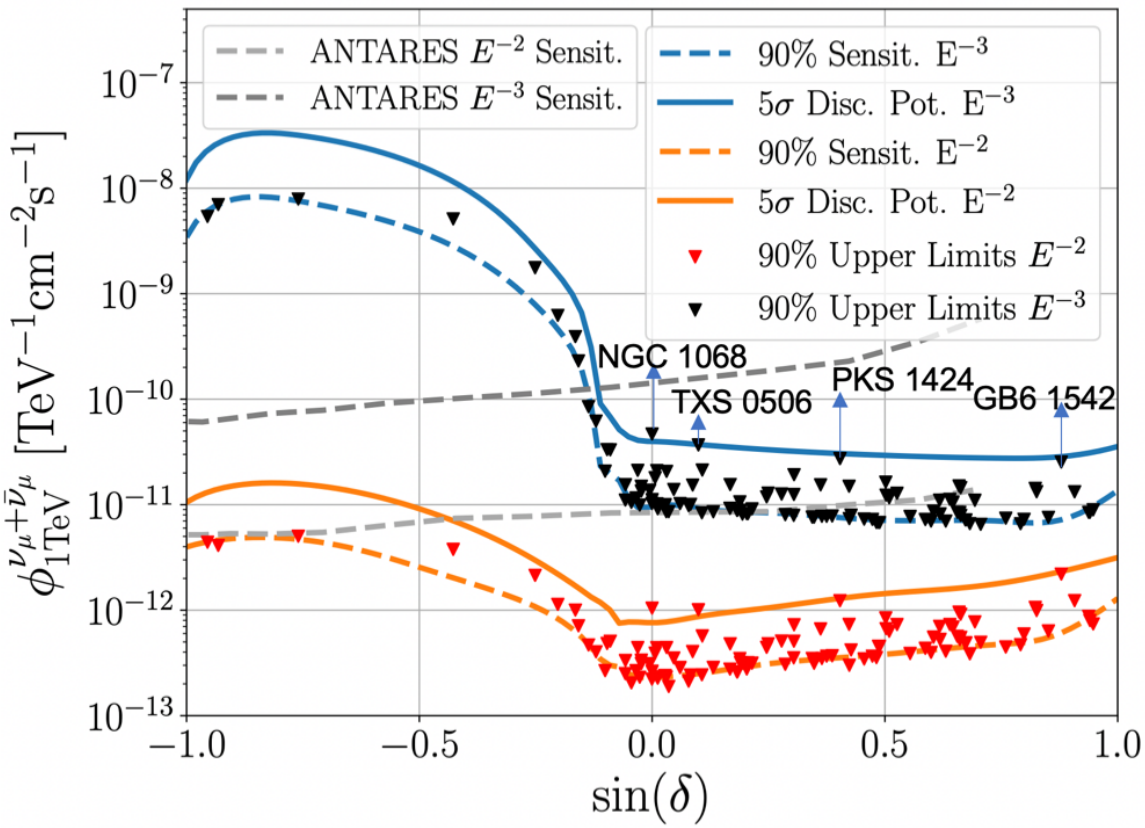
138322 neutrino candidates in one year

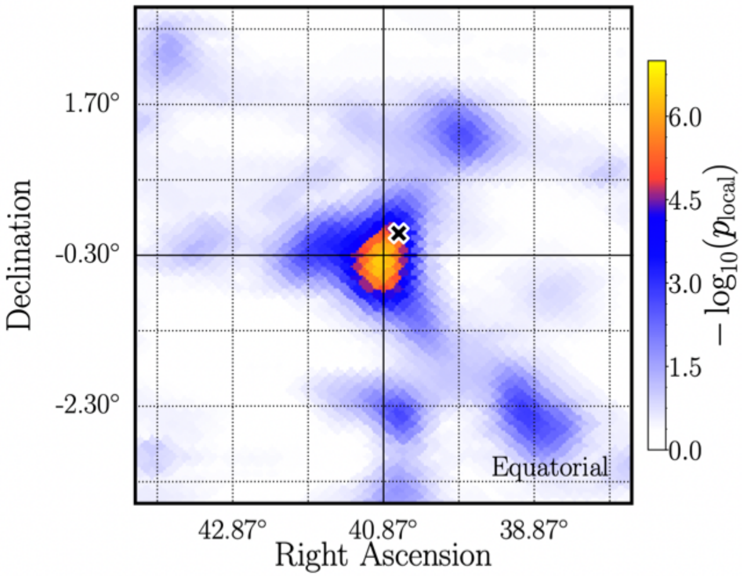
120 cosmic neutrinos

~12 separated from atmospheric background with E>60 TeV

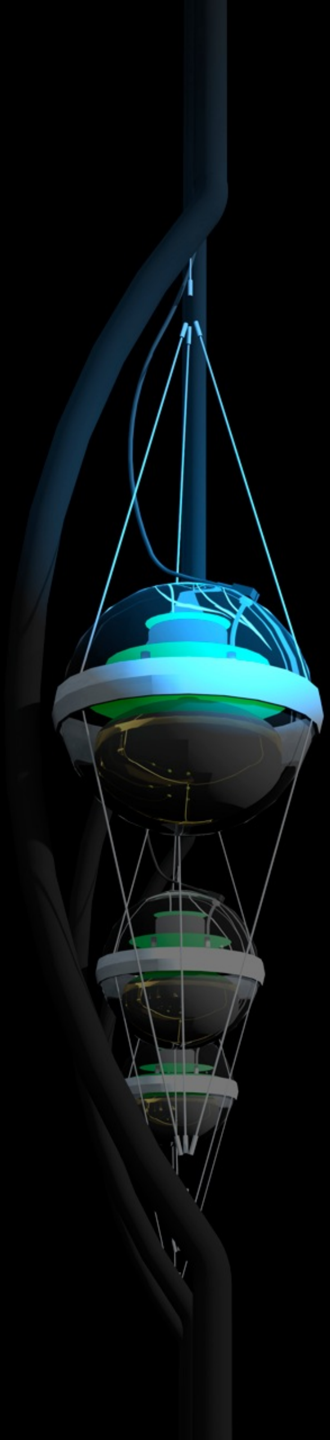
structure in the map results from neutrino absorption by the Earth

10 years of IceCube data: evidence for non-uniform skymap, mostly resulting from 4 source candidates





hottest spot: NGC 1068



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- multimessenger astronomy from TeV to radio
- a new class of sources?

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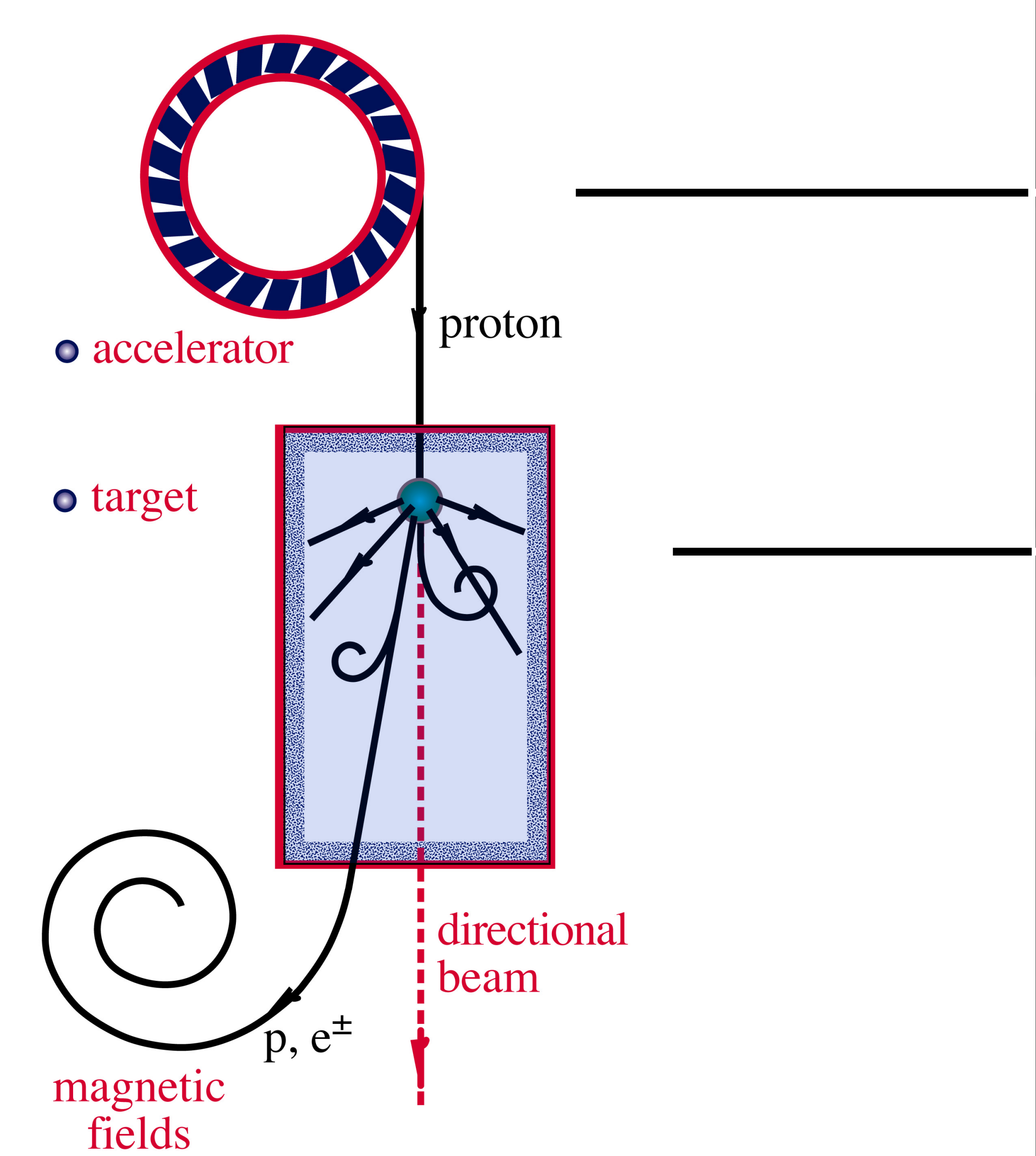
ν and γ beams : heaven and earth



accelerator is powered by large gravitational energy

black hole
neutron star

radiation and dust

$$p + \gamma \rightarrow n + \pi^+$$

~ cosmic ray + neutrino

$$\rightarrow p + \pi^0$$

~ cosmic ray + gamma

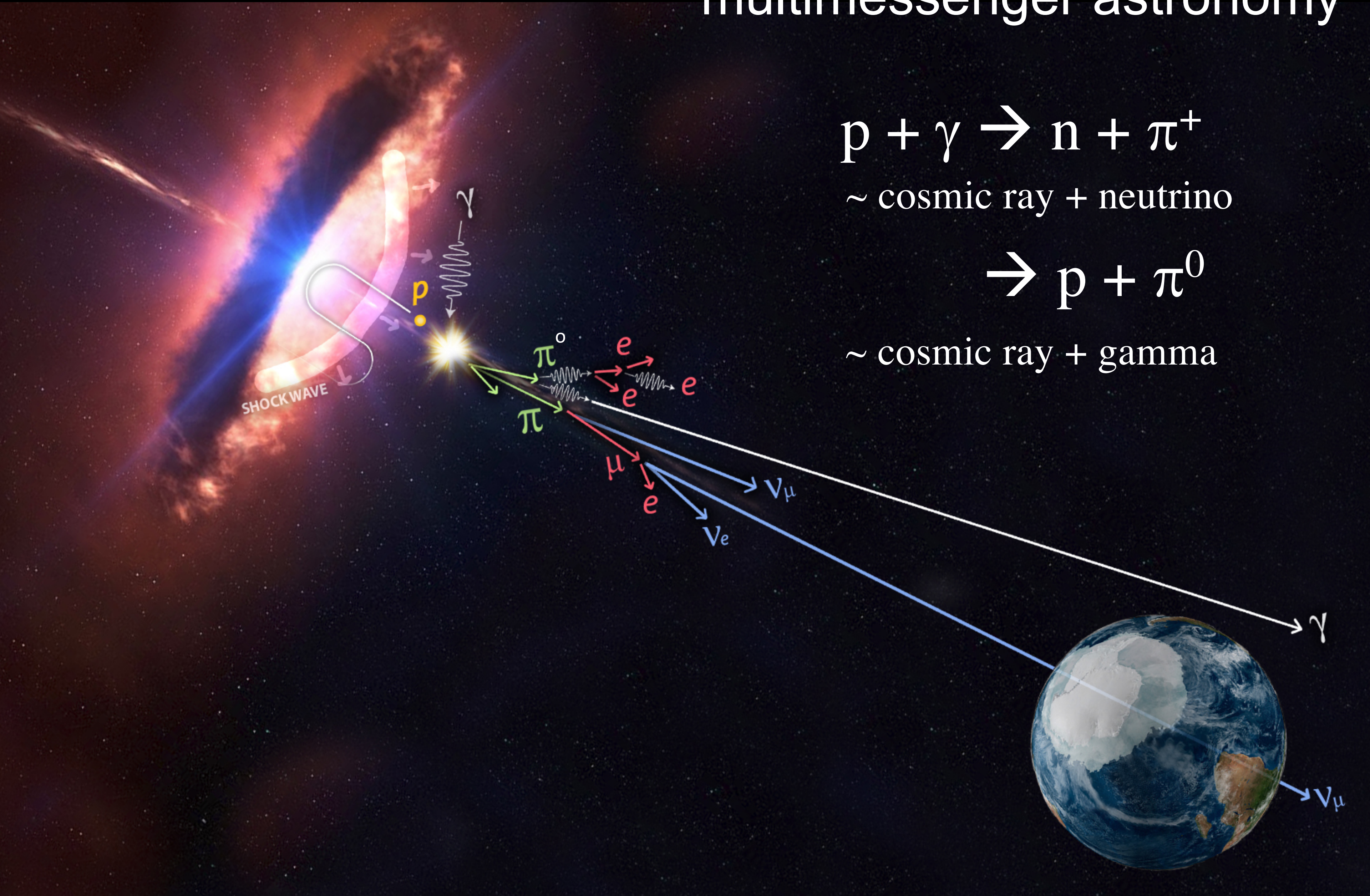
multimessenger astronomy

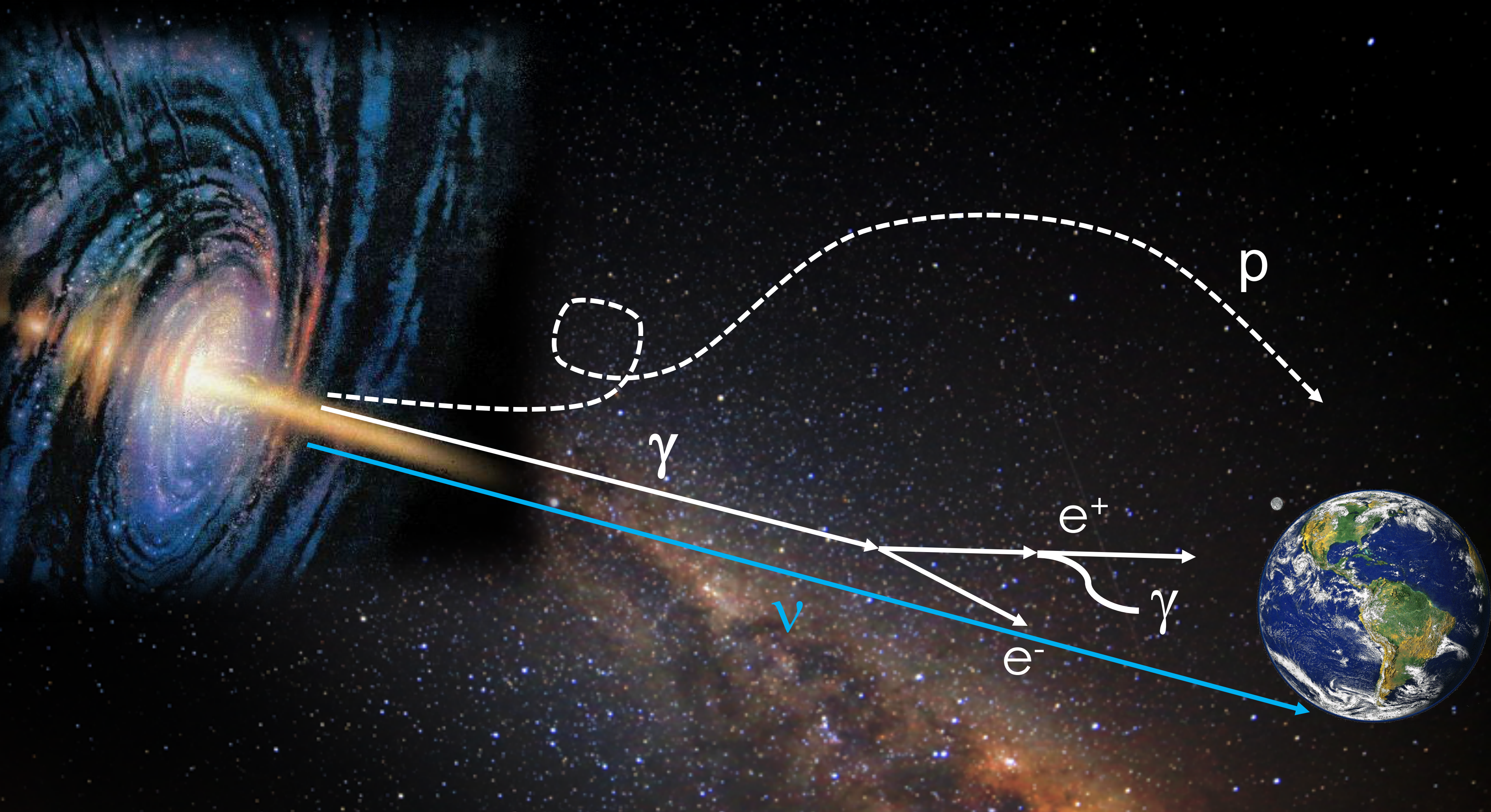
$$p + \gamma \rightarrow n + \pi^+$$

~ cosmic ray + neutrino

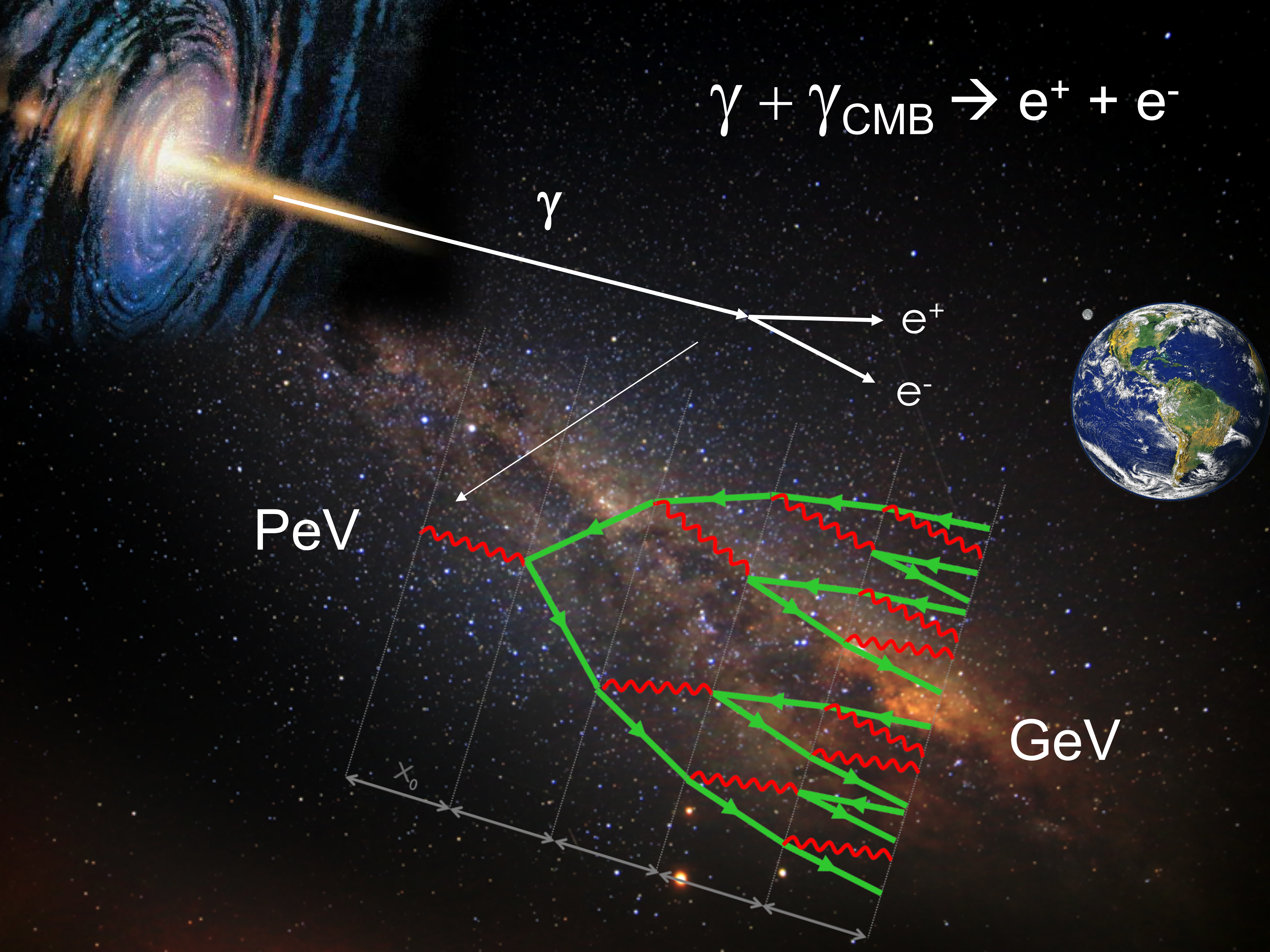
$$\rightarrow p + \pi^0$$

~ cosmic ray + gamma

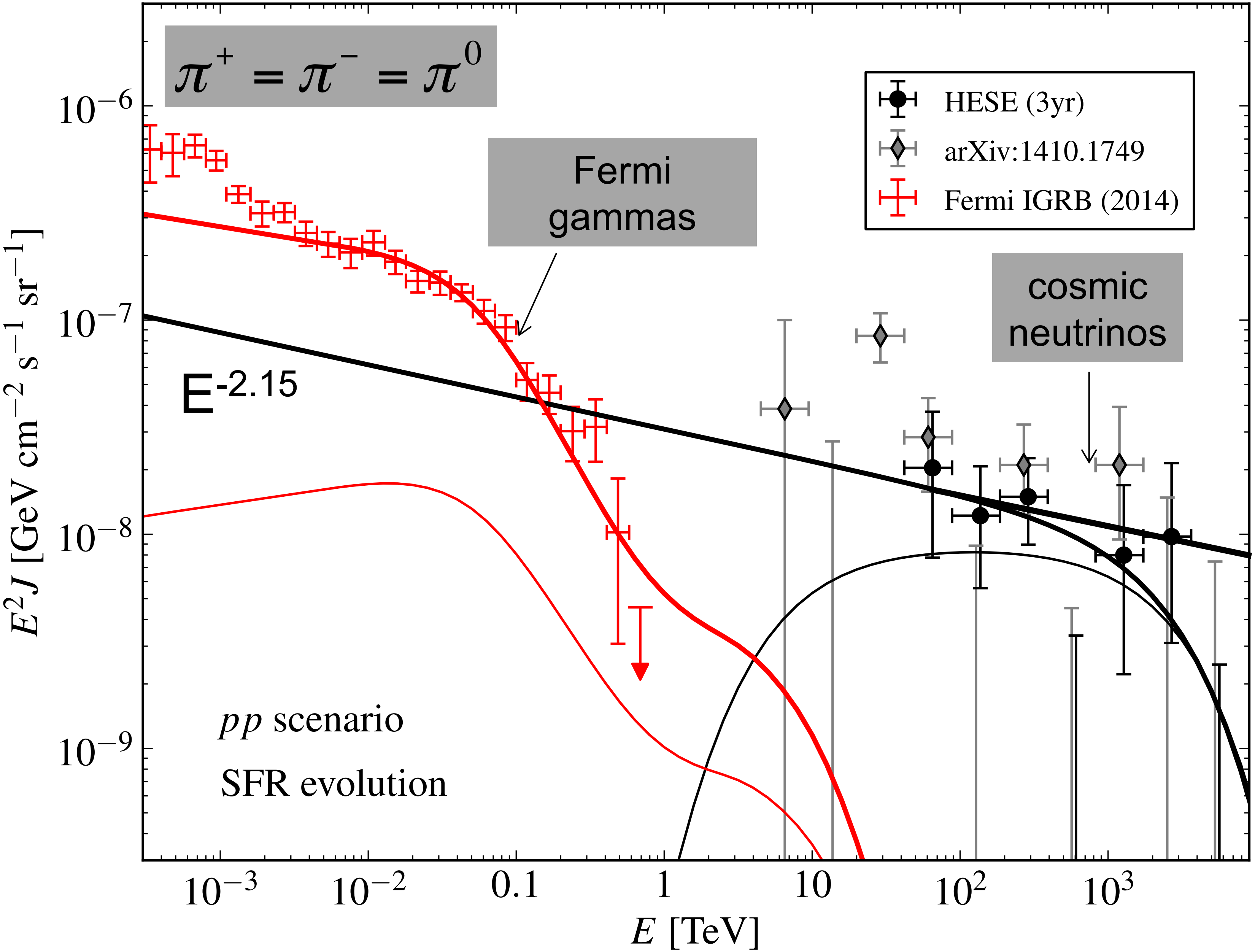




gamma rays accompanying IceCube neutrinos interact with interstellar photons and fragment into multiple lower energy gamma rays that reach earth

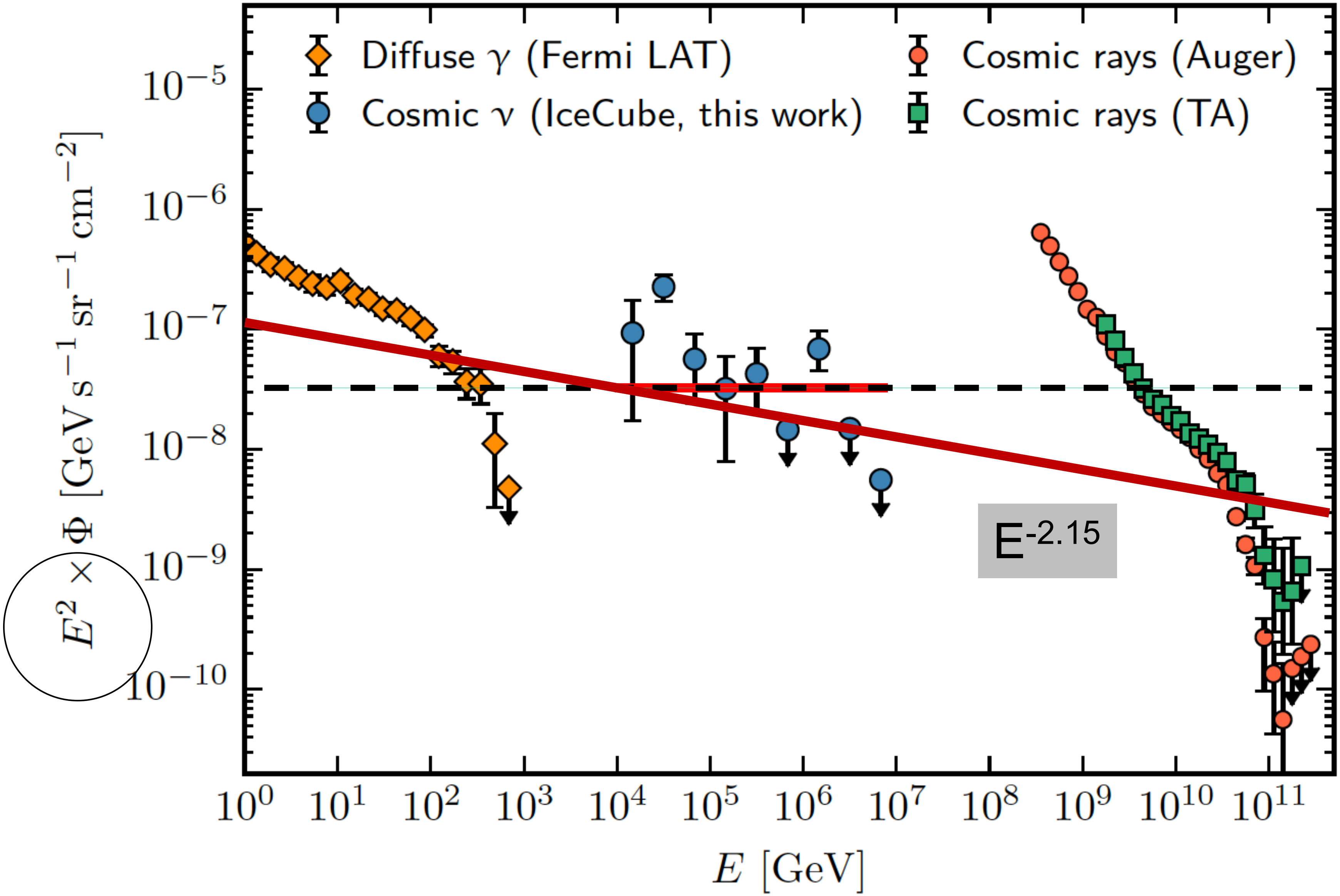


$\gamma + \gamma_{CMB} \rightarrow e^+ + e^-$
γ
e^+
e^-
PeV
GeV
X_0

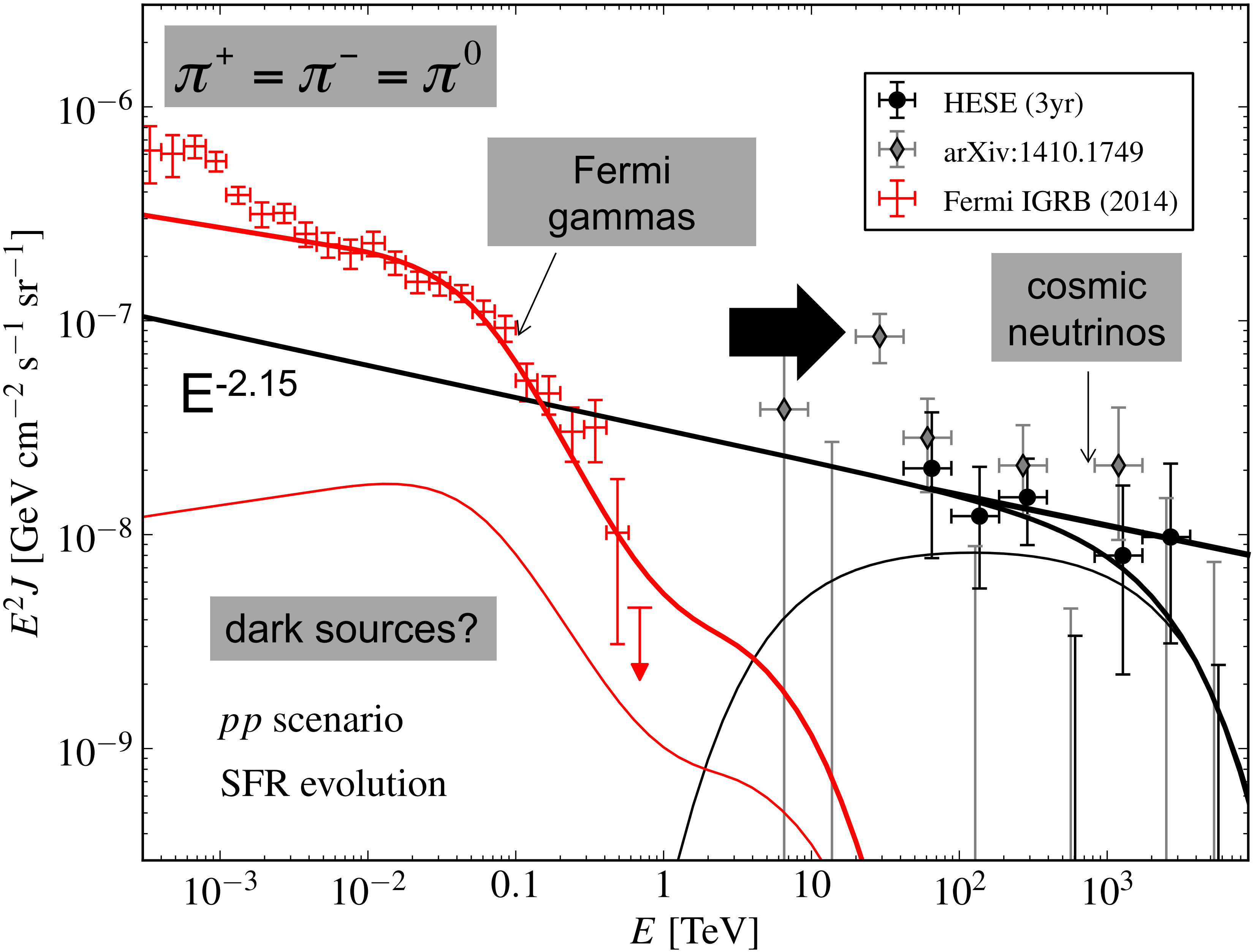


$\pi^+ = \pi^- = \pi^0$
HESE (3yr)
arXiv:1410.1749
Fermi IGRB (2014)
Fermi gammas
cosmic neutrinos
$E^{-2.15}$
pp scenario
SFR evolution
$E^2 J$ [GeV cm^{-2} s^{-1} sr^{-1}]
E [TeV]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-3}
10^{-2}
0.1
1
10
10^2
10^3

- energy density of neutrinos in the non-thermal Universe is the same as that in gamma-rays



energy in the Universe in gamma rays, neutrinos and cosmic rays



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cosmic neutrinos
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dark sources?
pp scenario
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E [TeV]
10^{-6}
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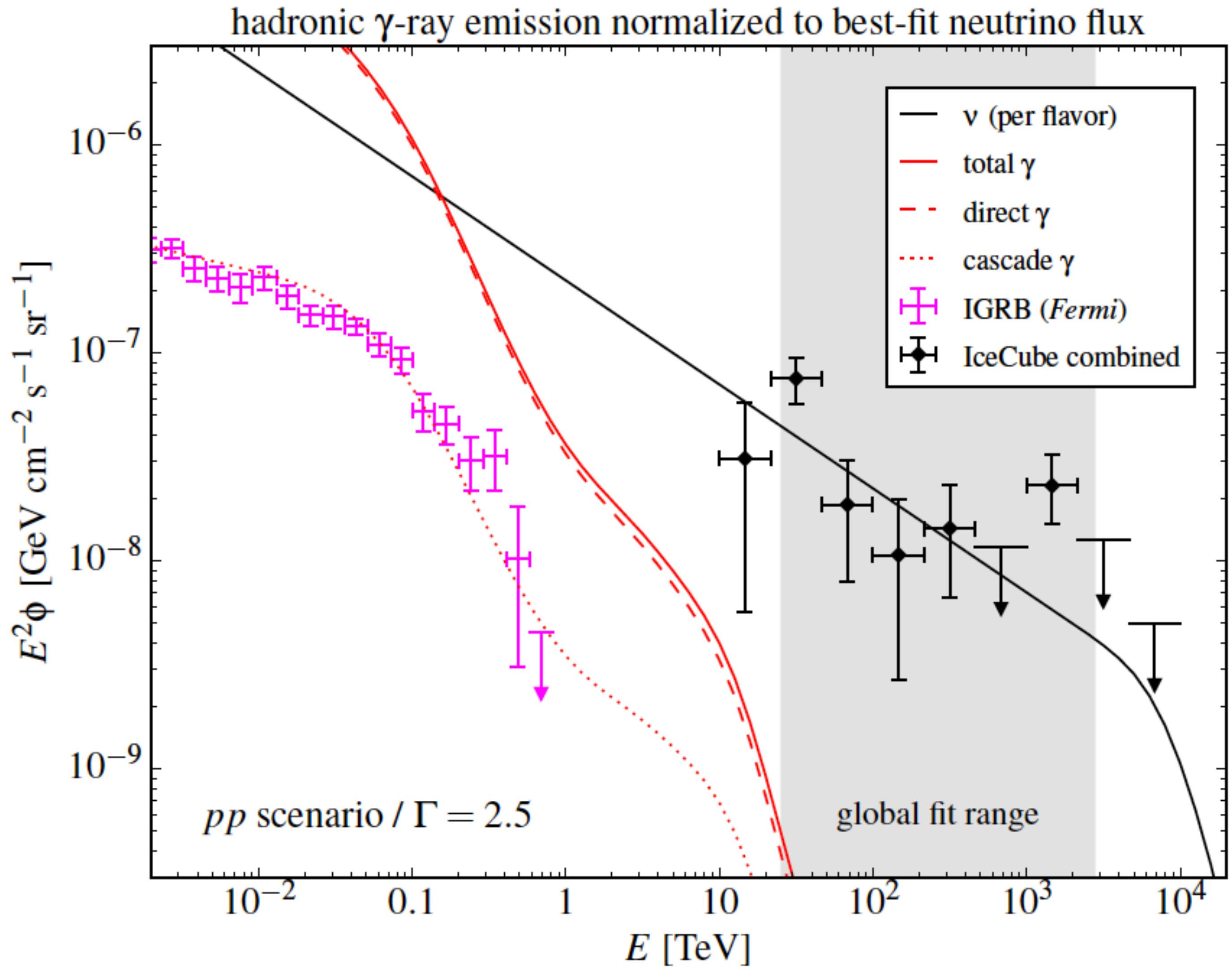
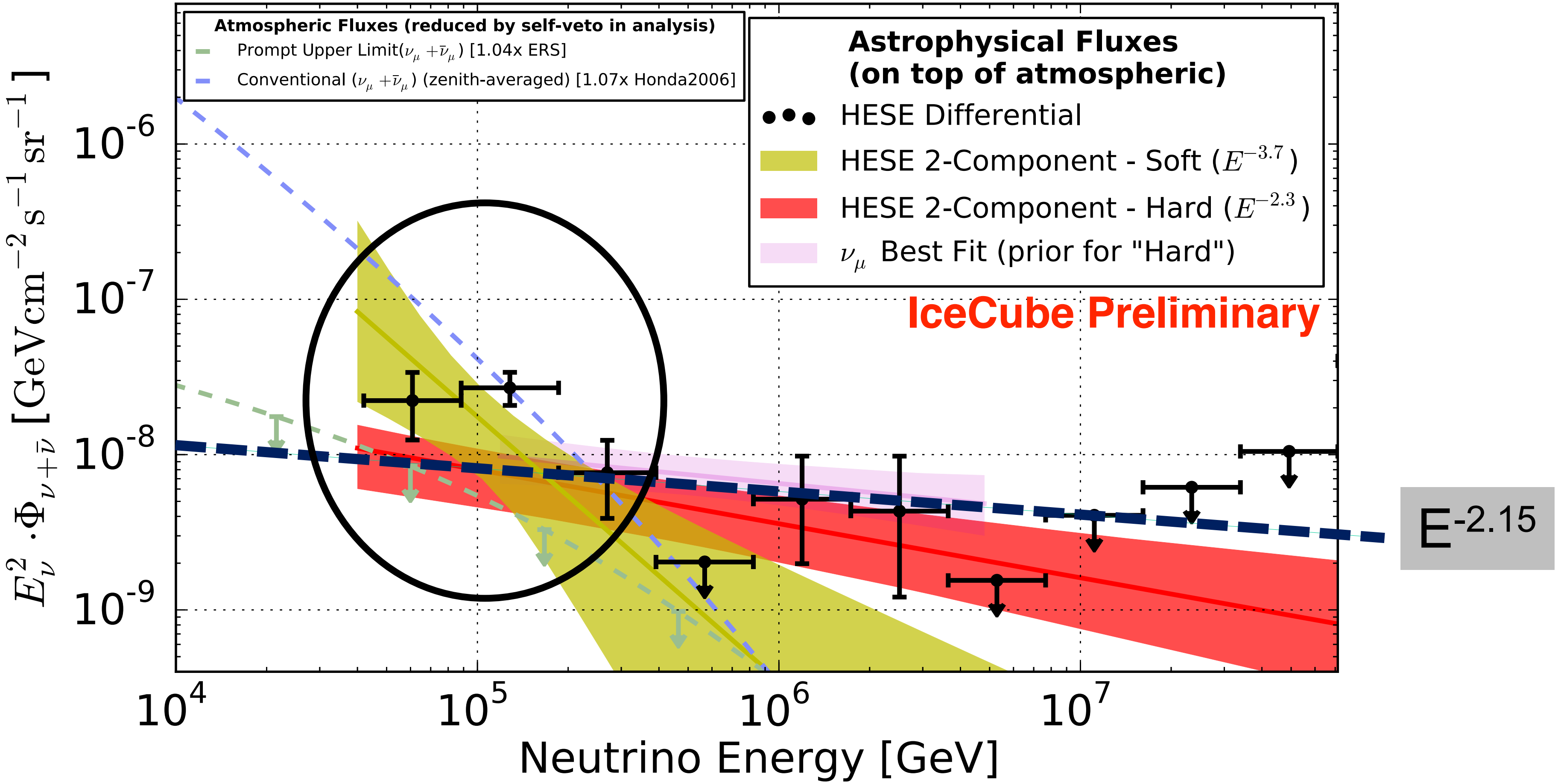
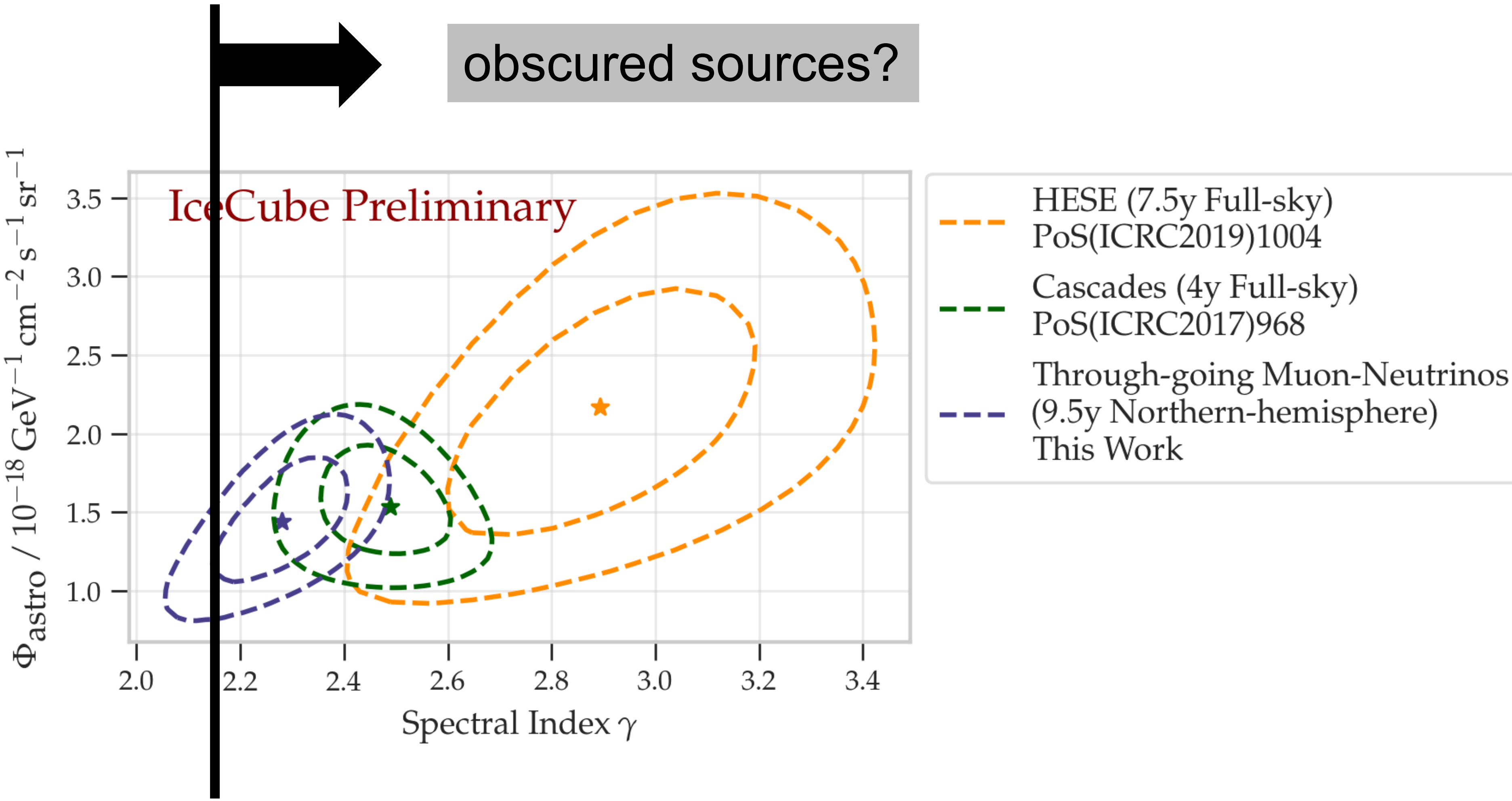
10^{-8}
10^{-9}
10^{-3}
10^{-2}
0.1
1
10
10^2
10^3

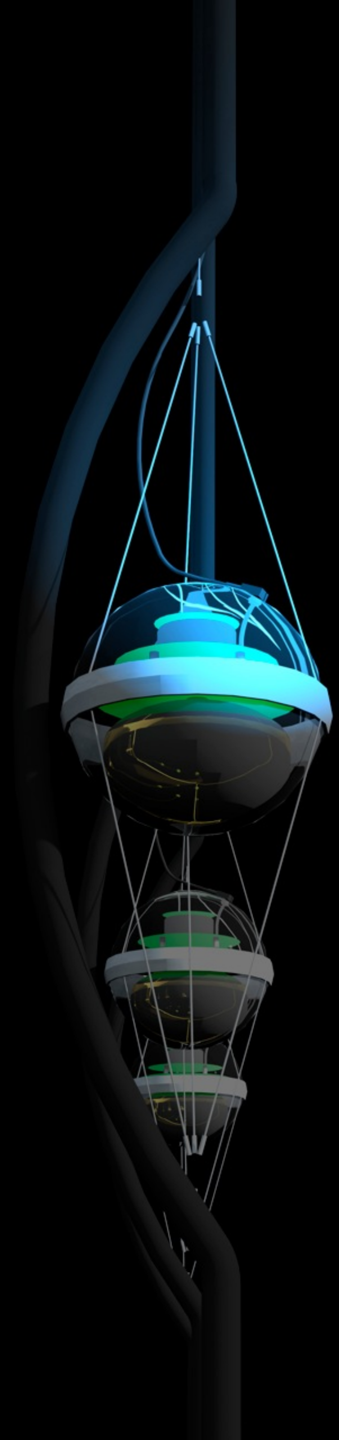


dark sources below 100 TeV not seen in γ's ?
gamma rays cascade *in the source* to lower energy
even before reaching the EBL



excess gamma rays relative to Fermi flux? Obscured sources?


obscured sources?
IceCube Preliminary
HESE (7.5y Full-sky)
PoS(ICRC2019)1004
Cascades (4y Full-sky)
PoS(ICRC2017)968
Through-going Muon-Neutrinos
(9.5y Northern-hemisphere)
This Work
Φ_{astro} / 10^{-18} GeV^{-1} cm^{-2} s^{-1} sr^{-1}
Spectral Index γ
3.5
3.0
2.5
2.0
1.5
1.0
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4



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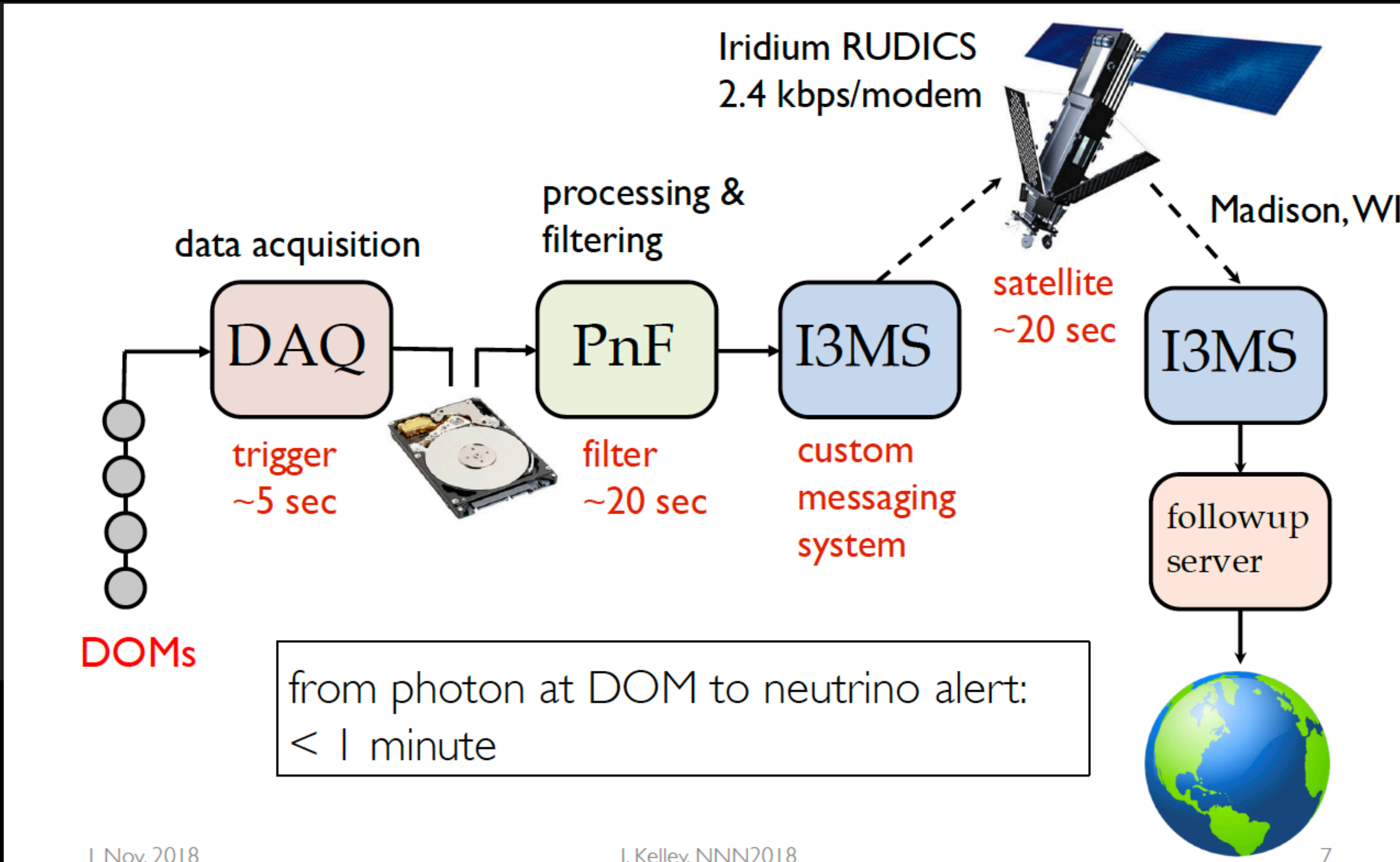
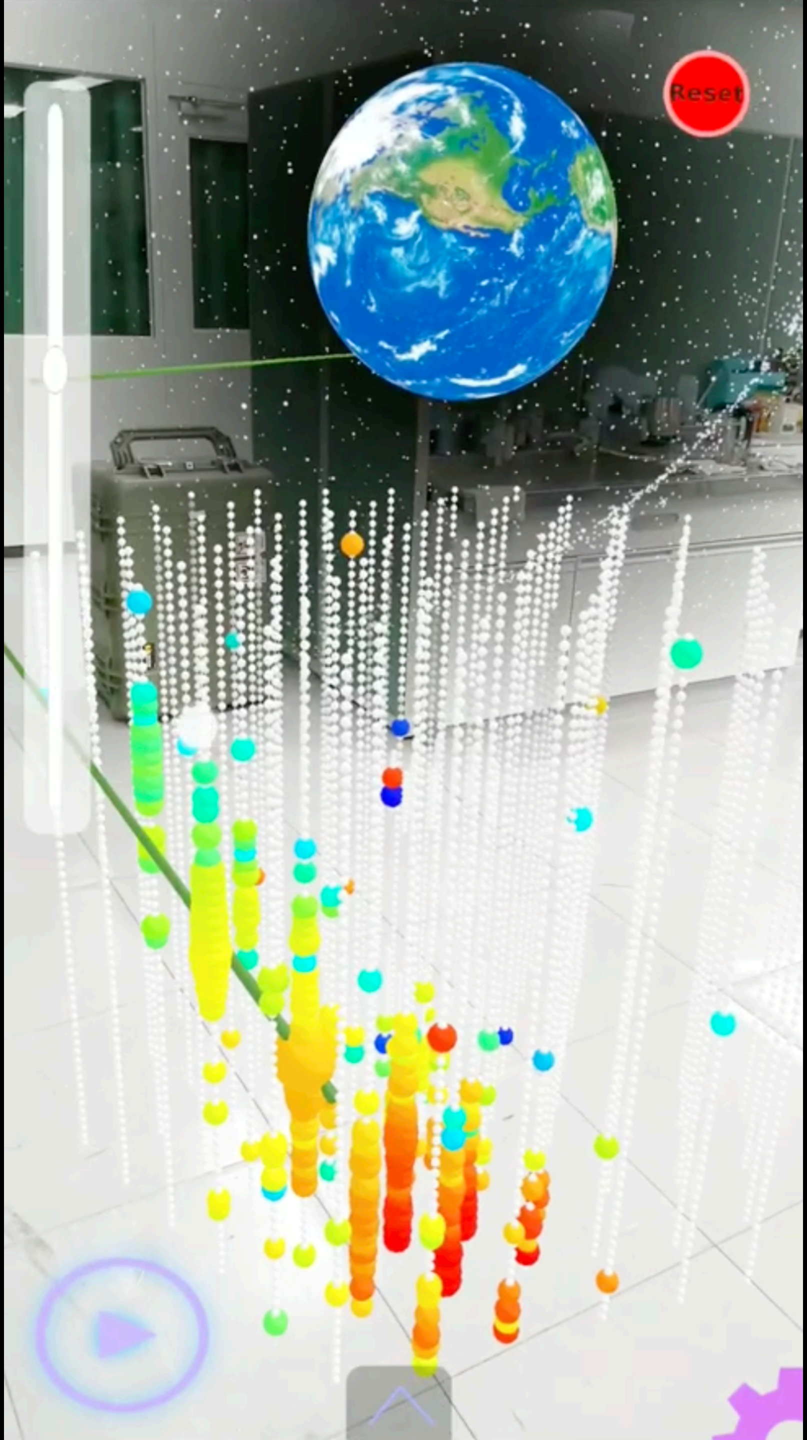
HIGH-ENERGY EVENTS NOW PUBLIC ALERTS!

We send our high-energy events in real-time as public GCN alerts now!



my phone



IceCube Trigger

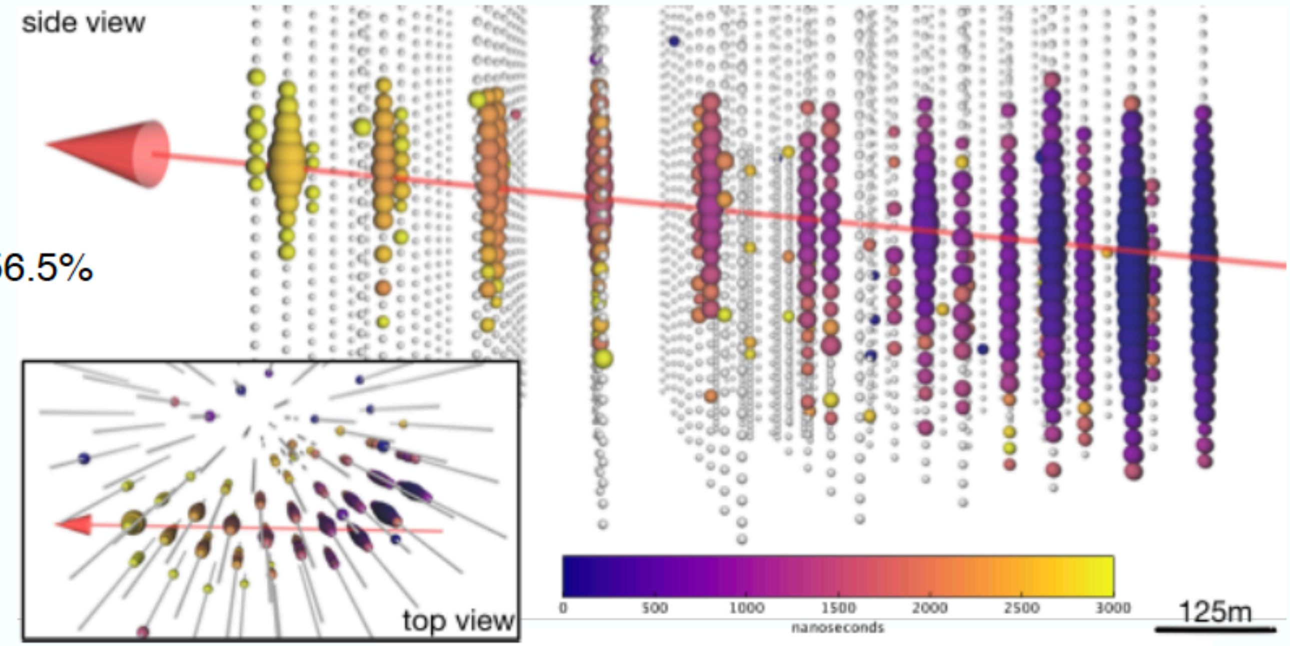
43 seconds after trigger, GCN notice was sent

```
//////////////////////////////////////////////////////////////////////
TITLE:            GCN/AMON NOTICE
NOTICE_DATE:      Fri 22 Sep 17 20:55:13 UT
NOTICE_TYPE:      AMON ICECUBE EHE
RUN_NUM:          130033
EVENT_NUM:        50579430
SRC_RA:            77.2853d {+05h 09m 08s} (J2000),
                   77.5221d {+05h 10m 05s} (current),
                   76.6176d {+05h 06m 28s} (1950)
SRC_DEC:           +5.7517d {+05d 45' 06"} (J2000),
                   +5.7732d {+05d 46' 24"} (current),
                   +5.6888d {+05d 41' 20"} (1950)
SRC_ERROR:        14.99 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18018 TJD;   265 DOY;   17/09/22 (yy/mm/dd)
DISCOVERY_TIME:   75270 SOD {20:54:30.43} UT
REVISION:         0
N_EVENTS:         1 [number of neutrinos]
STREAM:           2
DELTA_T:          0.0000 [sec]
SIGMA_T:          0.0000e+00 [dn]
ENERGY :          1.1998e+02 [TeV]
SIGNALNESS:       5.6507e-01 [dn]
CHARGE:           5784.9552 [pe]
```

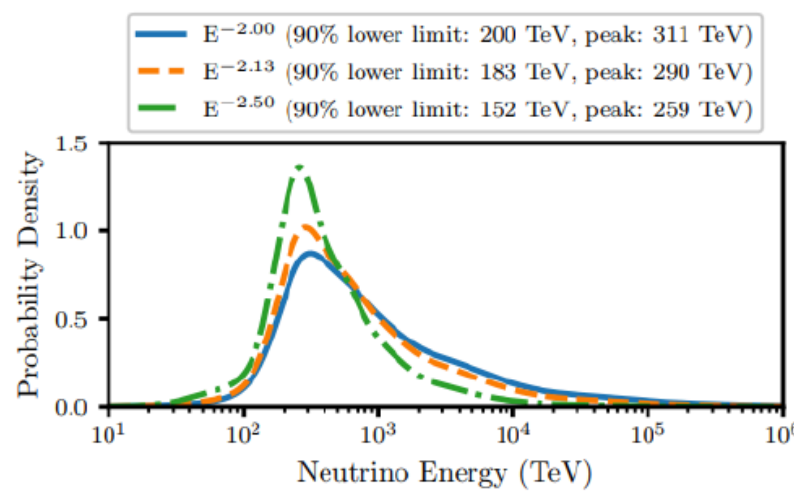
IC-170922A

23.7±2.8 TeV muon energy loss in the detector, 15 arcmin error (50% containment)

Signalness: 56.5%



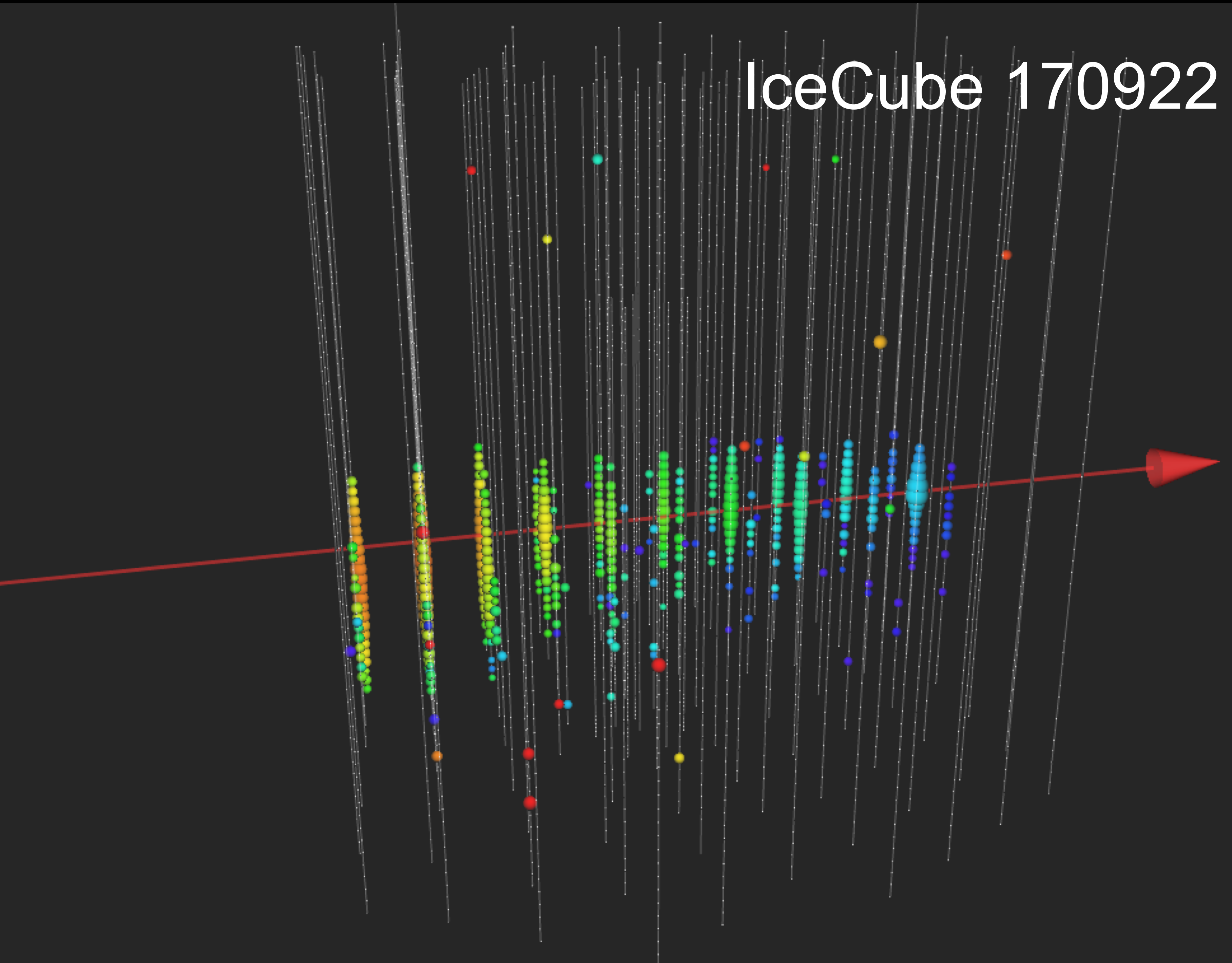
Most probable neutrino energy ~290 TeV. Upper limit at 90% CL is 4.5 PeV (7.5) PeV) for a spectral index of -2.13 (-2).



IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA, Science 2018

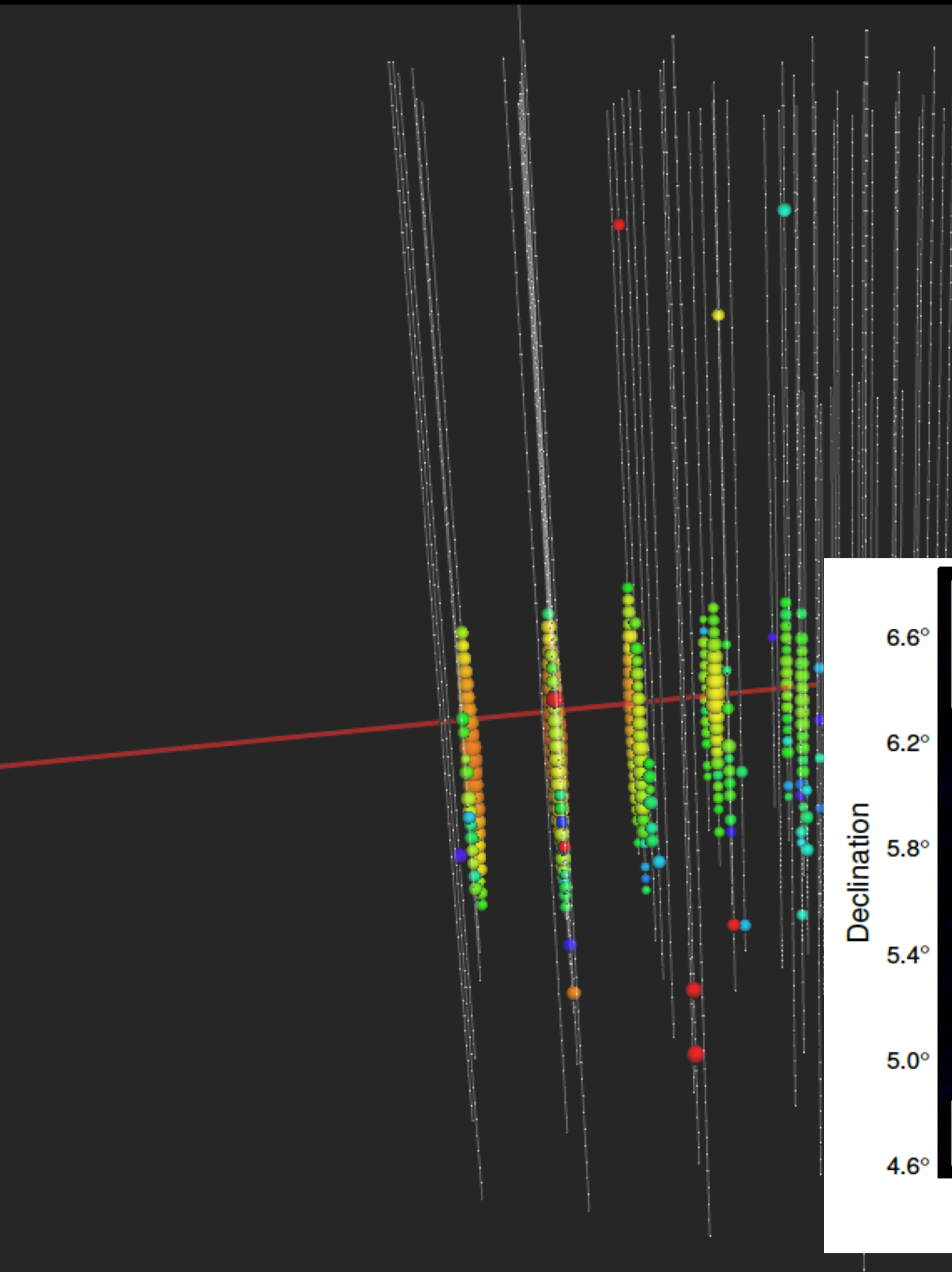
https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon

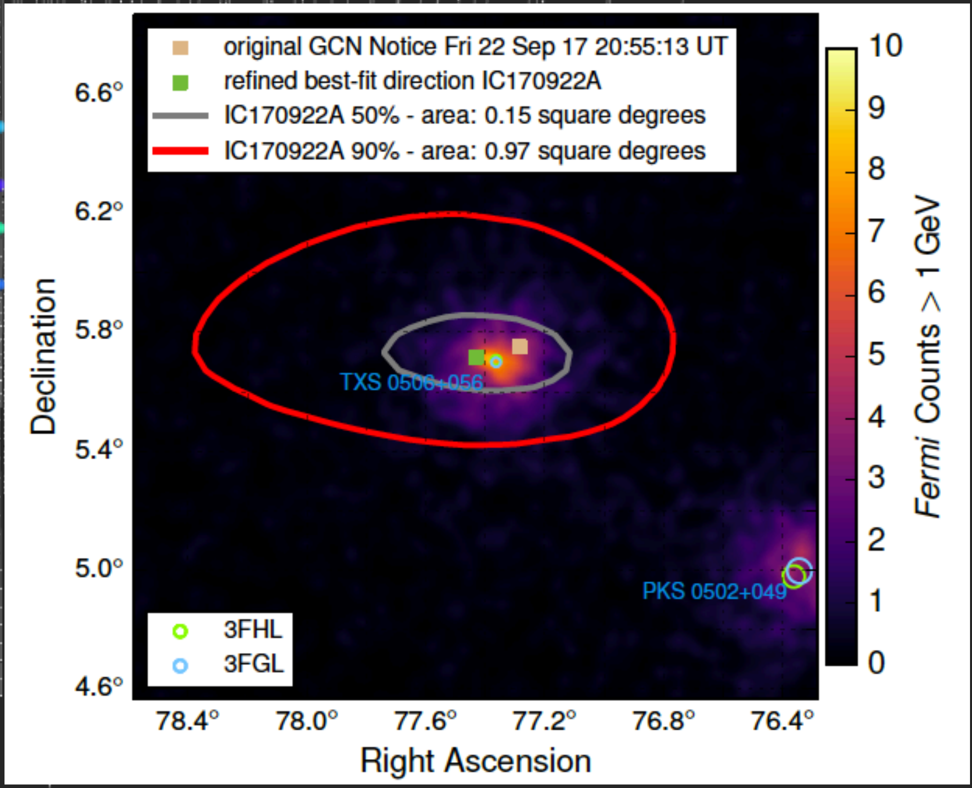
IceCube 170922



IceCube 170922

Fermi
detects a flaring
blazar within 0.06°





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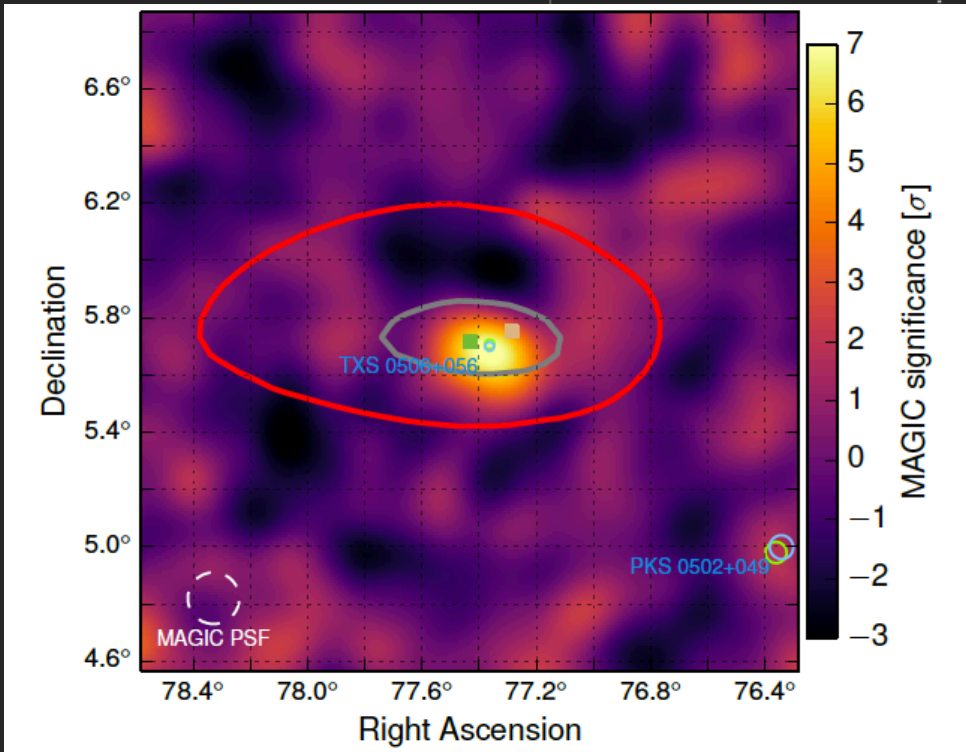
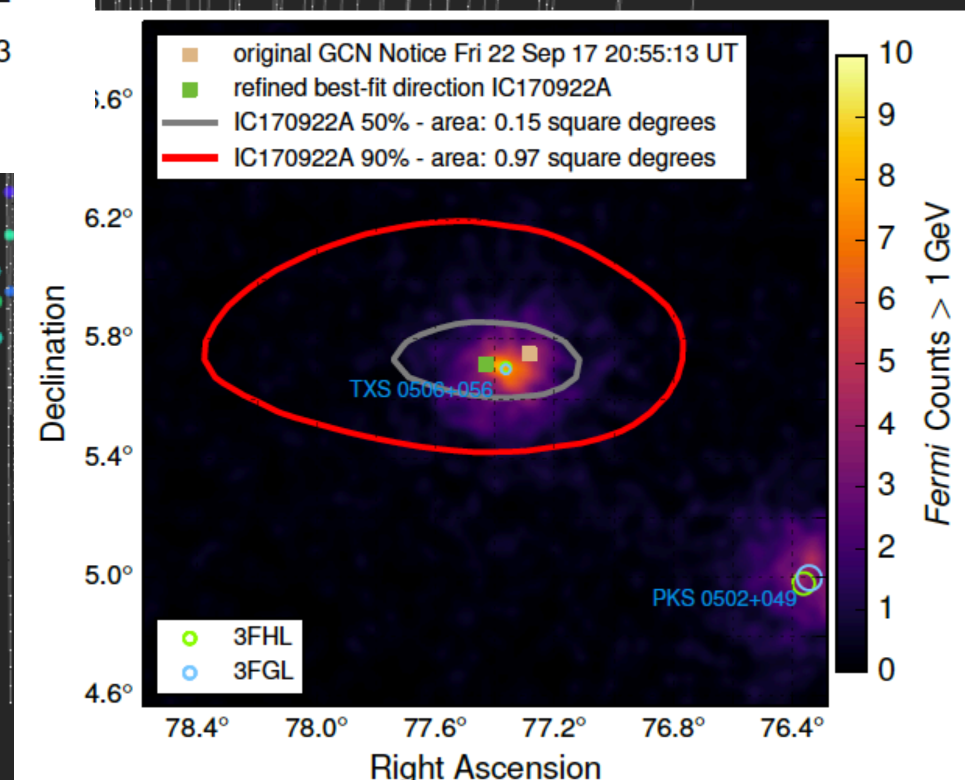


MAGIC
detects emission of
> 100 GeV gammas



THE REDSHIFT OF THE BL LAC OBJECT TXS 0506+056.

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[2] *INFN, Sezione di Padova, via Marzolo 8, I-35131 Padova - ITALY*
[3] *Università degli Studi dell'Insubria, Via Valleggio 11 I-22100 Como - ITALY*
[4] *INAF, Osservatorio Astronomico di Brera, Via E. Bianchi 46 I-23807 Merate (LC) - ITALY*
[5] *Instituto de Astrofisica de Canarias, C/O Via Lactea, s/n E38205 - La Laguna (Tenerife) - SPAIN*
[6] *Universidad de La Laguna, Dpto. Astrofisica, s/n E-38206 La Laguna (Tenerife) - SPAIN*

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Submitted to ApJL

arXiv:1802.01939v1 [astro-ph.GA] 6 Feb 2018

ABSTRACT

The bright BL Lac object TXS 0506+056 is a most likely counterpart of the IceCube neutrino event EHE 170922A. The lack of this redshift prevents a comprehensive understanding of the modeling of the source. We present high signal-to-noise optical spectroscopy, in the range 4100-9000 Å, obtained at the 10.4m Gran Telescopio Canarias. The spectrum is characterized by a power law continuum and is marked by faint interstellar features. In the regions unaffected by these features, we found three very weak (EW $\sim$ 0.1 Å) emission lines that we identify with [O II] 3727 Å, [O III] 5007 Å, and [NII] 6583 Å, yielding the redshift z = 0.3365±0.0010.

Keywords: galaxies: BL Lacertae objects: individual (TXS 0506+056) – distances and redshifts – gamma rays: galaxies –neutrinos

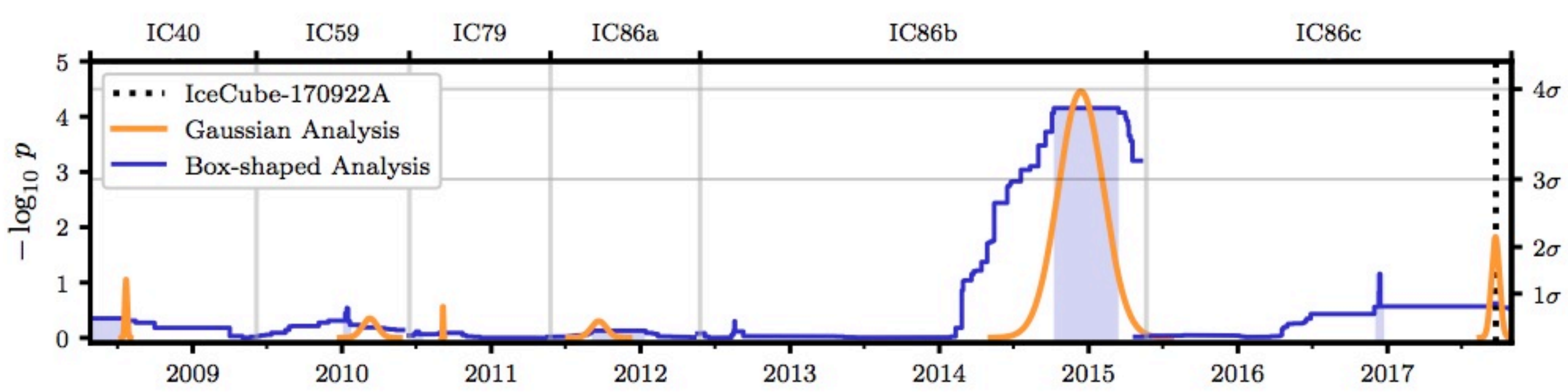
z = 0.34

at ten times further distance, it outshines nearby active galaxies: is it special?

multiwavelength campaign launched by IC 170922

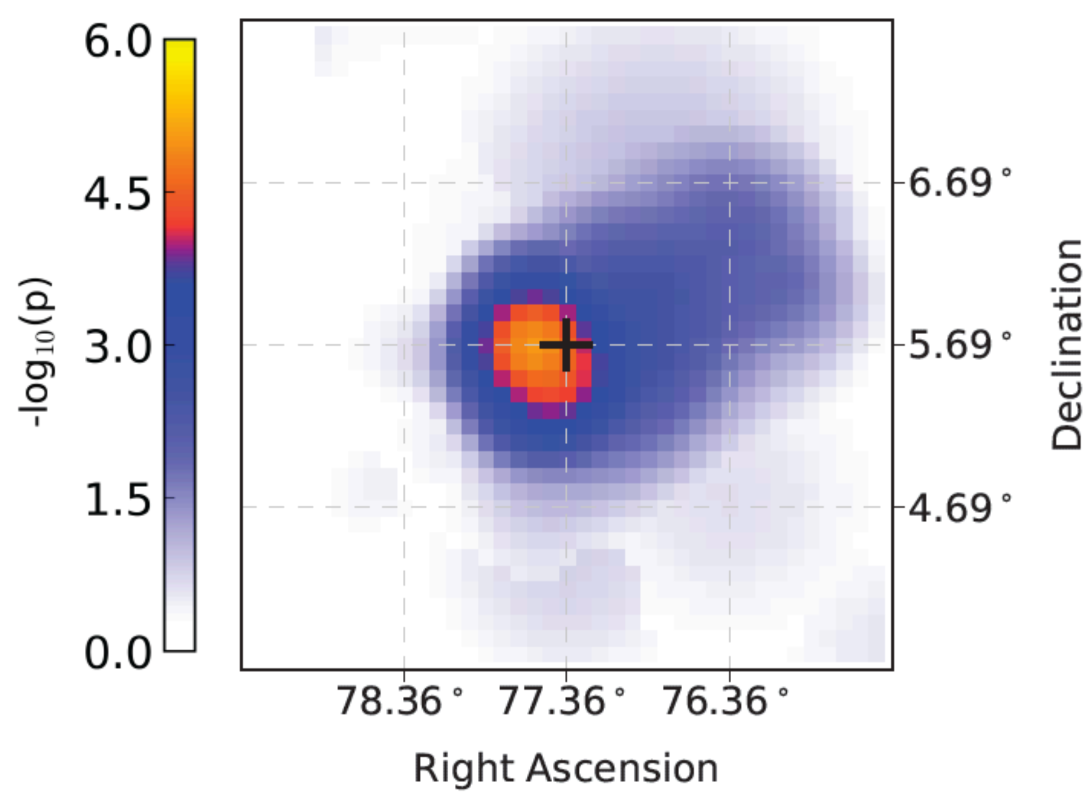
IceCube, *Fermi* –LAT, MAGIC, Agile, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, KISO, Liverpool, Subaru, *Swift*, VLA, VERITAS

- neutrino: time 22.09.17, 20:54:31 UTC
  energy 290 TeV
  direction RA 77.43^{o} Dec 5.72^{o}
- Fermi-LAT: flaring blazar within 0.1^{o} (7x steady flux)
- MAGIC: TeV source in follow-up observations
- follow-up by 12 more telescopes
- → IceCube archival data (without look-elsewhere effect)
- → Fermi-LAT archival data

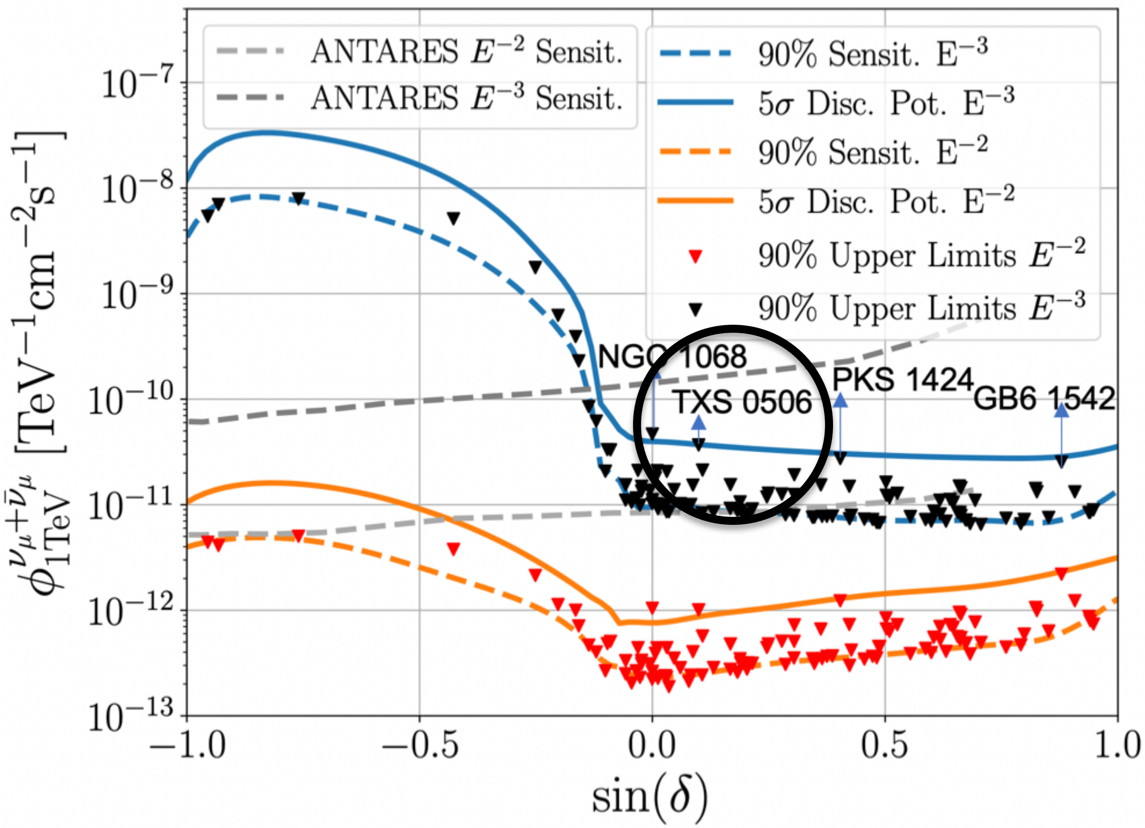


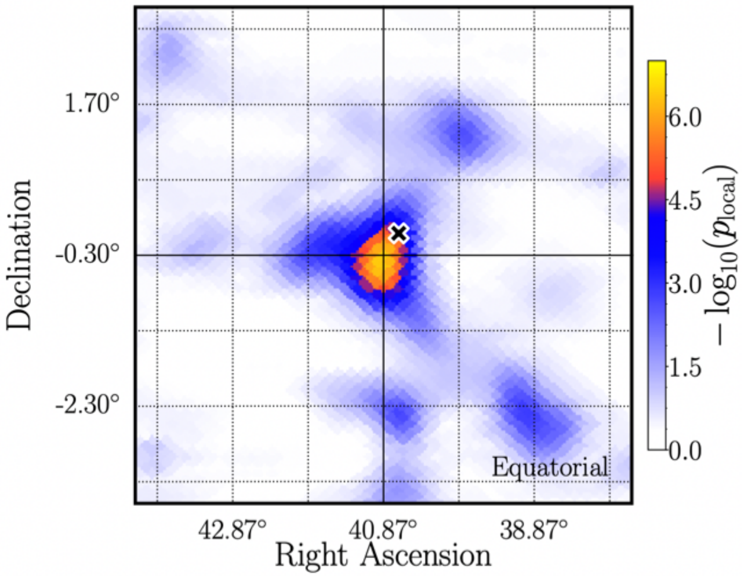
search in archival IceCube data:

- 150 day flare in December 2014 of 19 events (bkg <6)
- 2.10^{-5} bkg.probability
- spectrum $E^{-2.1}$



why not seen before?





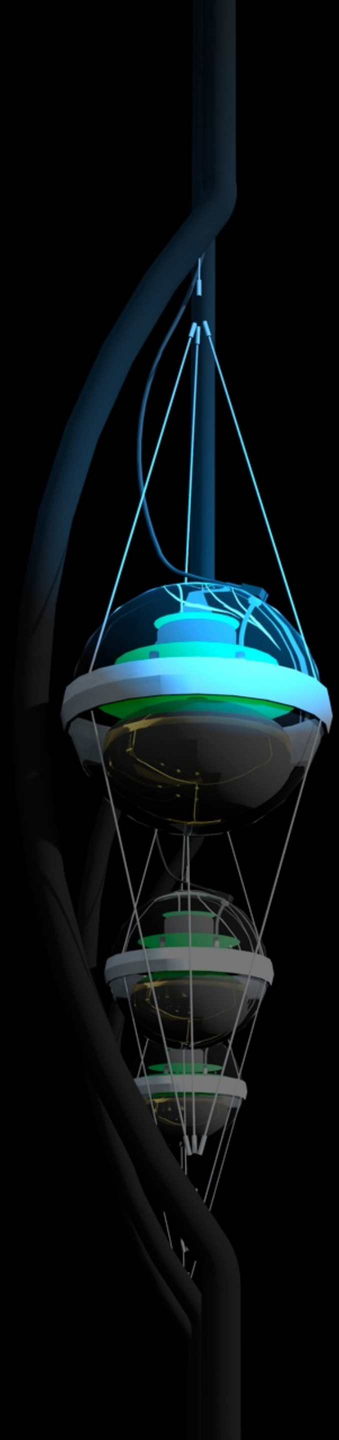
hottest spot: NGC 1068

we identified a source of high energy cosmic rays:

the active galaxy (blazar) TXS 0506+056 at a redshift of 0.33

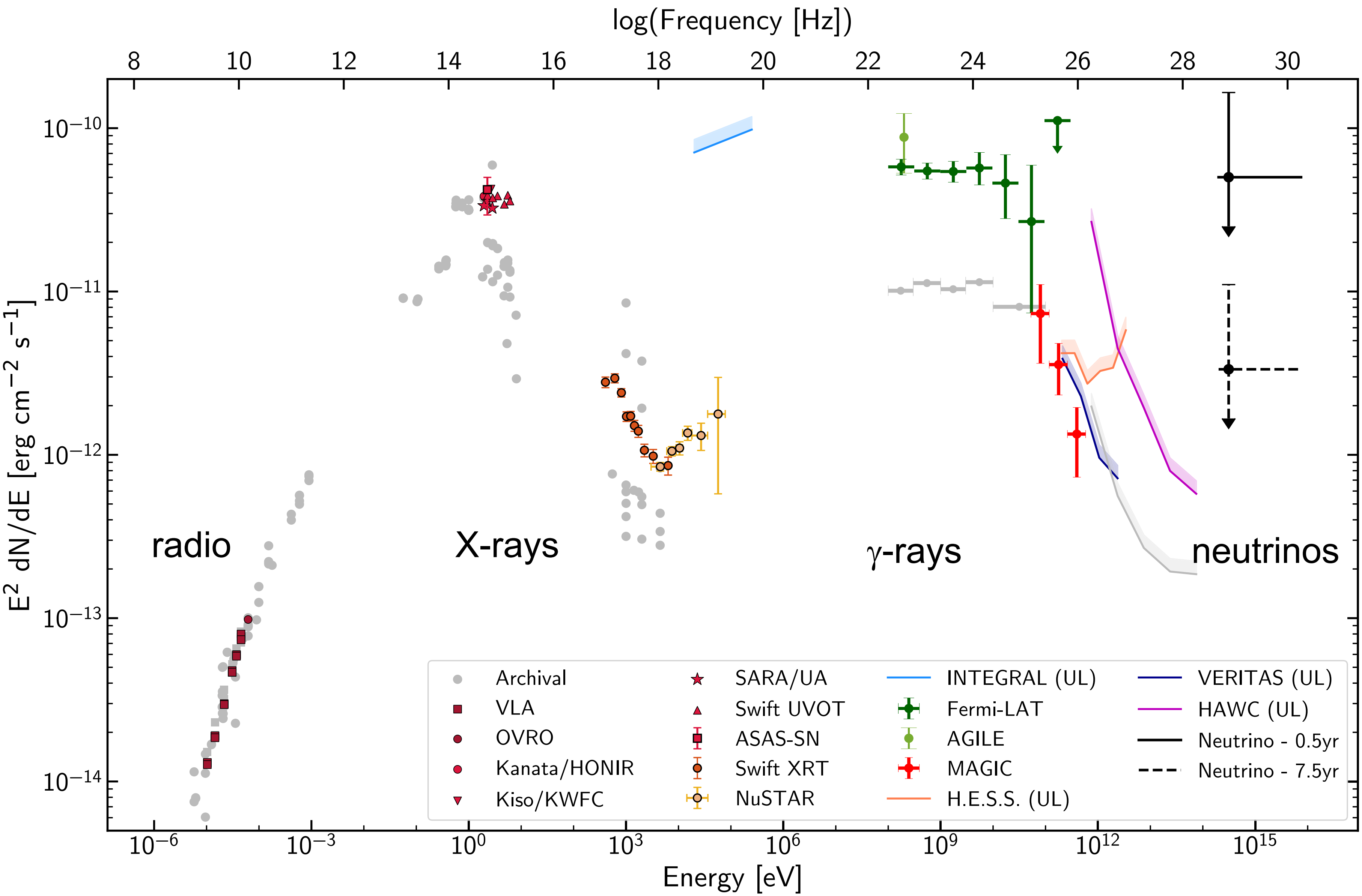
at ten times further distance, it outshines nearby active galaxies: is it special?

extensive multiwavelength campaign will allow us to study the first cosmic accelerator



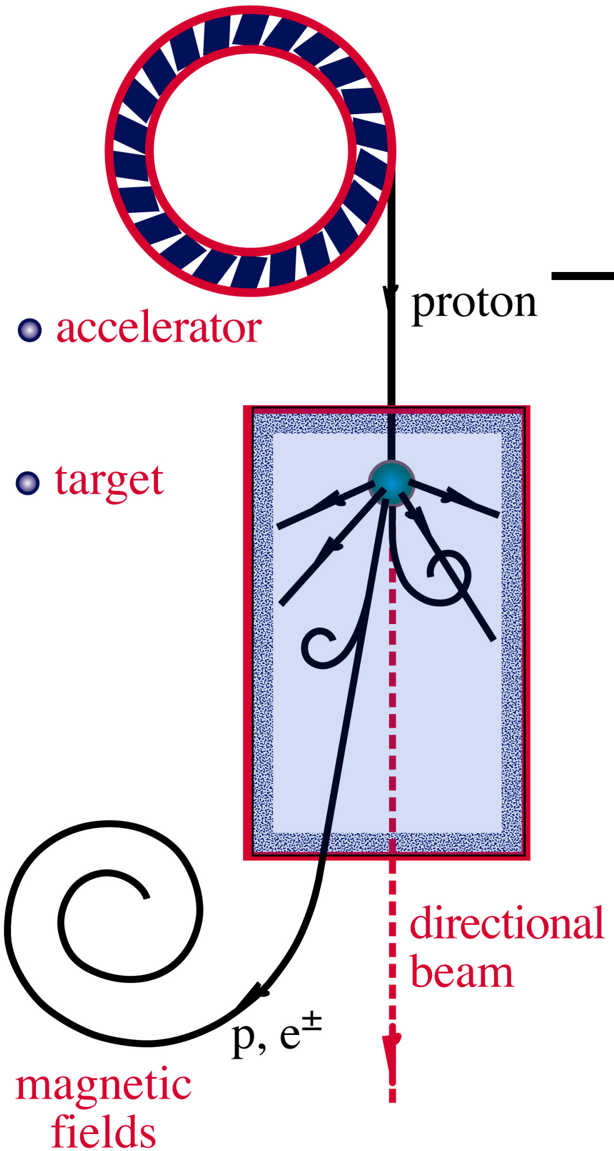
- cosmic neutrinos: four independent observations
  → muon neutrinos through the Earth
  → starting neutrinos: all flavors
  → high energy tau neutrinos
  → a Glashow resonance event
- IceCube neutrinos and Fermi photons
- the cosmic ray accelerator TXS 0506+056
- multimessenger astronomy from radio to PeV neutrinos
- a new class of sources?

icecube.wisc.edu



we know that this “blazar” is a cosmic ray source

ν and γ beams : heaven and earth



$p + \gamma \rightarrow n + \pi^+$

$\rightarrow$ cosmic ray + neutrino

black hole
neutron star

radiation
and dust

neutrino source
needs an accelerator
and
a target
source opacity?

<u>some points regarding the TXS 0506+056 neutrino source:</u>

- a blazar jet is transaparent to high energy gamma rays and therfore does not have the target density to produce neutrinos ($\sigma_{\gamma\gamma} >> s_{p\gamma}$)

- if every "blazar" produced neutrinos at the level of TXS 0506+056, the sources would overproduce the total flux observed by IceCube by a factor of 20.

- TXS 0506+056 must indeed belong to a special subclass of sources, as already suggested by the large distance.

- a source that produces 13 neutrinos in 110 days has a target density for producing neutrinos that is large and it must therefore be opaque to high-energy gamma rays.

  It takes a major accretion event onto the black hole to accommodate the target density required to accommodate the 2014-15 observation.

  the 2014-15 burst cannot be, and is not, accompanied by a Fermi flare.

- details at arXiv:1811.07439 and arXiv:1811.07439

relation between flaring sources and the diffuse flux ?

diffuse ν_μ flux

TXS luminosity

$$\boxed{\sum_\alpha E_\nu^2 \frac{dN_\nu}{dE_\nu} = \frac{1}{4\pi}\frac{c}{H_0}\xi_z L_\nu \rho \mathcal{F}\frac{\Delta t}{T}}$$

density of blazars

$$\sum_\alpha E_\nu^2 \frac{dN_\nu}{dE_\nu} \simeq 7.4 \times 10^{-9}\,\mathrm{TeV cm^{-2} s^{-1} sr^{-1}} \simeq$$

0.05 $\longleftrightarrow$

$$\left(\frac{\mathcal{F}}{4\pi}\right)\left(\frac{c/H_0}{4.3\,\mathrm{Gpc}}\right)\left(\frac{\xi_z}{0.7}\right)\left(\frac{L_\nu}{1.2\times 10^{47}\,\mathrm{erg/s}}\right)$$

$$\left(\frac{\rho}{1.5\times 10^{-8}\,\mathrm{Mpc}^{-3}}\right)\left(\frac{\Delta t}{110\,\mathrm{d}}\right)\left(\frac{10\,\mathrm{yr}}{T}\right).$$

a target that produces > 12 neutrinos in 110 days is opaque to gamma rays
that lose energy in the source even before entering the EBL

$$\boxed{\frac{1}{3}\sum_{\alpha} E_\nu^2 \frac{dN_\nu}{dE_\nu} \simeq \frac{c}{8\pi}\,\tau_{p\gamma}\,\xi_z\,t_H \left(\frac{dE}{dt}\right)_{\rm CR}}$$

accompanying photons
below Fermi threshold

proton beam normalized
to the energy density
in cosmic rays

$$\frac{dE}{dt} \simeq (1-2)\times 10^{44}\,\mathrm{erg\,Mpc^{-3}\,yr^{-1}}$$

$$\tau_{\gamma\gamma} \approx \frac{\eta_{\gamma\gamma}\sigma_{\gamma\gamma}}{\eta_{p\gamma}\hat{\sigma}_{p\gamma}}\tau_{p\gamma}$$

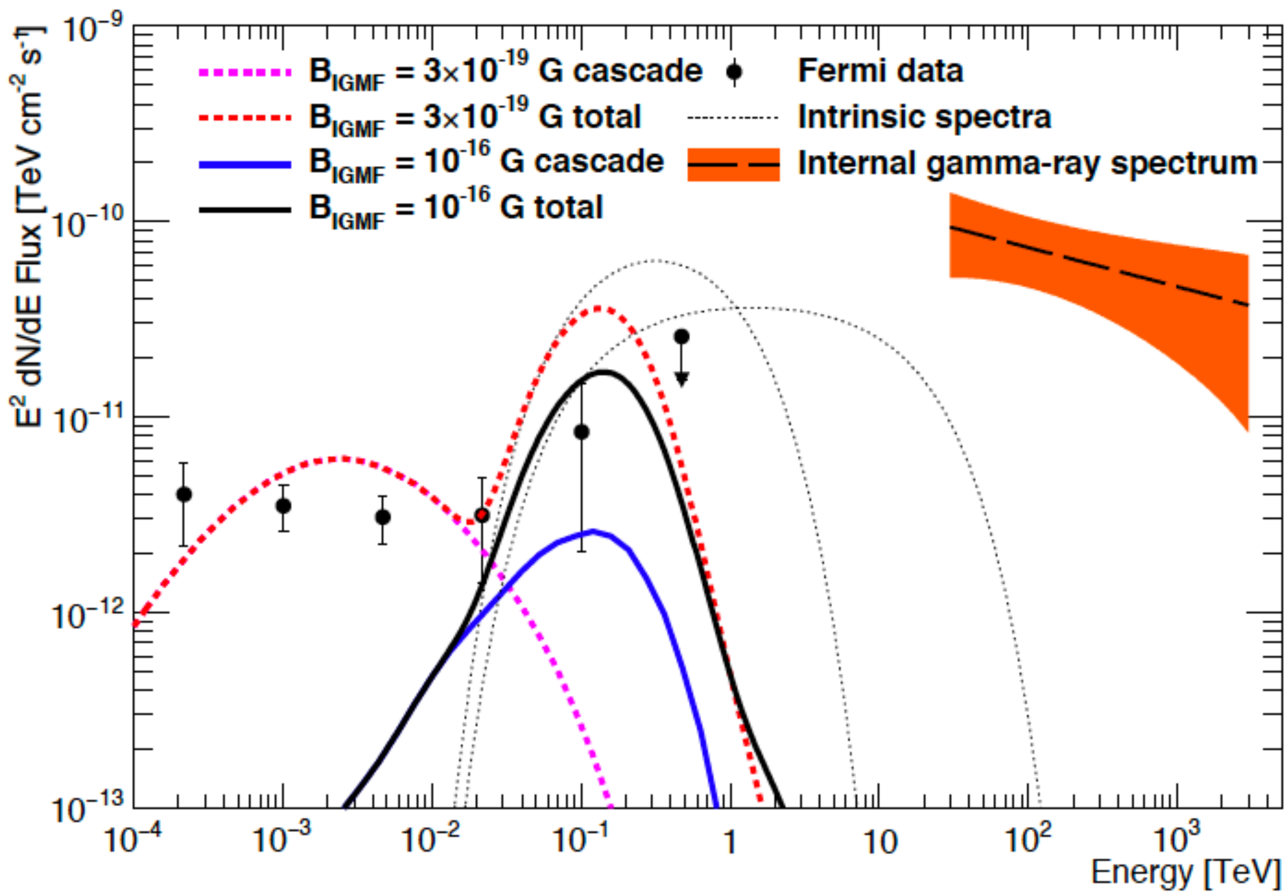
the gamma rays that
accompany the neutrinos
lose energy in the source

$$\tau_{p\gamma} \gtrsim 0.4$$

opacity of the gamma
ray target

the multimessenger picture: gamma ray energy (mostly) below Fermi threshold

neutrino flux $\xrightarrow{\text{multimessenger relation}}$ gamma ray flux cascades to lower energy in the source $\xrightarrow{\text{EBL absorption}}$ observed flux @ Fermi



**Fermi data from S. Garrappa+, TeVPA2018*

consistent with the expectation for individual sources

blobs in agn jets: protons interact with synchrotron photons produced by co-accelerated electrons

$$1 - e^{-\tau_{p\gamma}} = \frac{a L_\gamma}{E_\gamma} \frac{1}{\Gamma^2 \Delta t} \frac{3\,\sigma_{p\gamma}}{4\pi c^2}$$

$$1 - e^{-\tau_{p\gamma}} \geq 0.4$$

$$\simeq \left[\frac{a}{10\%}\right]\left[\frac{L_\gamma}{2\times 10^{46}\mathrm{erg\,s^{-1}}}\right]\left[\frac{10\,\mathrm{eV}}{E_\gamma}\right]\left[\frac{1}{\Gamma^2}\right]\left[\frac{110\,\mathrm{d}}{\Delta t}\right]\left[\frac{3\,\sigma_{p\gamma}}{4\pi c^2}\right]$$

- a: efficiency to convert gamma ray luminosity L_γ to synchrotron target photons of energy 10 eV

- Δt: duration of the burst.

consistent with the expectation for individual sources

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- a: efficiency to convert gamma ray luminosity L_γ to synchrotron target photons of energy 10 eV

- Δt: duration of the burst.

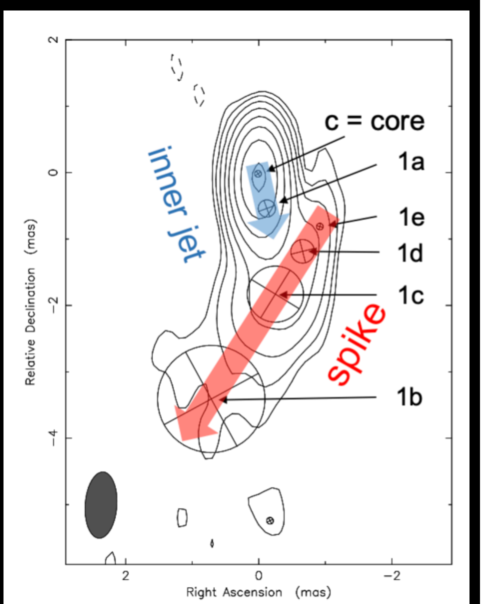
vanilla blazars cannot accommodate the 2014 burst:

need major accretion on the black hole to provide a target that can produce the 2014-15 neutrino burst

TXS 0506+056 is a galaxy merger

"We thus observe the interaction between jet features that cross each other's paths."

theory confirms observation



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July 31, 2019

Erratum to: A&A, 630, A103 (2019), https://doi.org/10.1051/0004-6361/201935422

A Cosmic Collider: IceCube neutrino generated in a precessing jet-jet interaction in TXS 0506+056?

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Received September 15, 1996; accepted March 16, 1997

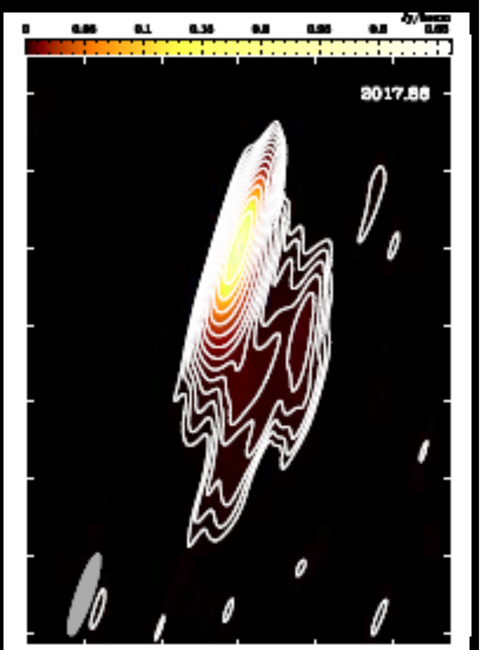
ABSTRACT

Context. The neutrino event IceCube-170922A appears to originate from the BL Lac object TXS 0506+056. To understand the neutrino creation process and localize the emission site, we studied the radio images of the jet at 15 GHz.
Aims. Other BL,Lac objects show similar properties as TXS 0506+056, such as multi-wavelength variability or a curved jet. However, so far, only TXS 0506+056 has been identified as neutrino emitter. This paper aims to figure out, what makes the pc-scale jet of TXS 0506+056 specific in this respect.
Methods. We re-analyzed and re-modeled 16 VLBA 15 GHz observations between 2009 and 2018. We thoroughly examined the jet kinematics and flux-density evolution of individual jet components during the time of enhanced neutrino activity between Sept,2014 and March 2015, and in particular before and after the neutrino event.
Results. Our results suggest that the jet is very strongly curved and most likely observable under a special viewing angle of close to zero. We thus may observe the interaction between jet features which cross each others' paths. We find subsequent flux-density flaring of six components passing the likely collision site. In addition, we find strong indication for precession of the inner jet and model a precession period of about 10 yrs by the Lense-Thirring effect. We discuss an alternative scenario that is the interpretation of observing the signature of *two* jets within TXS 0506+056, again hinting towards a collision of jetted material. We essentially suggest that the neutrino emission may result from the interaction of jetted material in combination with a special viewing angle and jet precession.
Conclusions. We propose that the enhanced neutrino activity during the neutrino flare in 2014 - 2015 and the single EHE neutrino IceCube-170922A could be generated by a cosmic collision within TXS 0506+056. Our findings seem capable of explaining the neutrino generation at the time of a low gamma-ray flux and also indicate that TXS 0506+056 might be an atypical blazar. It seems to be the first time that (i) a potential collision of two jets on pc-scales is reported and that (ii) the detection of a cosmic neutrino might be traced back to a cosmic jet-collision.

TXS 0506+056 is a galaxy merger

"We thus observe the interaction between jet features that cross each other's paths."

theory confirms observation



Astronomy & Astrophysics manuscript no. 0506
December 5, 2019

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1912.01743v1 [astro-ph.GA] 3 Dec 2019

Letter to the Editor

Apparent superluminal core expansion and limb brightening in the candidate neutrino blazar TXS 0506+056

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7 National Aeronautics and Space Administration/Goddard Space Flight Center, Greenbelt, MD 20771, USA
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Submitted: November 28, 2019; Accepted: December 3, 2019

ABSTRACT

Context. IceCube has reported a very-high-energy neutrino (IceCube-170922A) in a region containing the blazar TXS 0506+056. Correlated gamma-ray activity has led to the first high-probability association of a high-energy neutrino with an extragalactic source. This blazar has been found to be in a radio outburst during the neutrino event.

Aims. Our goal is to probe the sub-milliarcsecond properties of the radio jet right after the neutrino detection and during the further evolution of the radio outburst.

Methods. We have performed target-of-opportunity very-long-baseline interferometry imaging observations at 43 GHz frequency, corresponding to 7 mm in wavelength, with the Very Long Baseline Array two and eight months, respectively, after the neutrino event.

Results. We produced two images of the radio jet of TXS 0506+056 at 43 GHz with angular resolutions of (0.2×1.1) mas and (0.2×0.5) mas, respectively. The source shows a compact, high brightness temperature core (albeit not approaching the equipartition limit, Readhead 1994) and a bright and originally very collimated inner jet. Beyond about 0.5 mas from the mm-VLBI core, the jet loses this tight collimation and expands rapidly. During the months after the neutrino event associated with this source, the overall flux density is rising. This flux density increase happens solely within the core. Notably, the core expands in size with apparent superluminal velocity during these six months so that the brightness temperature drops by a factor of three in spite of the strong flux density increase.

Conclusions. The radio jet of TXS 0506+056 shows strong signs of deceleration and/or a spine-sheath structure within the inner 1 mas (corresponding to about 70 pc to 140 pc in deprojected distance) from the mm-VLBI core. This structure is consistent with theoretical models that attribute the neutrino and gamma-ray production in TXS 0506+056 to interactions of electrons and protons in the highly-relativistic jet spine with external photons originating from a slower-moving jet region. Proton loading due to jet-star interactions in the inner host galaxy is suggested as the possible cause of deceleration.

Key words. Radiation mechanisms: non-thermal – Neutrinos – Techniques: interferometric – Radio continuum: galaxies – Galaxies: quasars: individual: TXS 0506+056

Mon. Not. R. Astron. Soc. **000**, 1–?? (0000) Printed 14 November 2018 (MN LaTeX style file v2.2)

VLBI radio structure and radio brightening of the high-energy neutrino emitting blazar TXS 0506+056

arXiv:1807.07942v2 [astro-ph.HE] 13 Nov 2018

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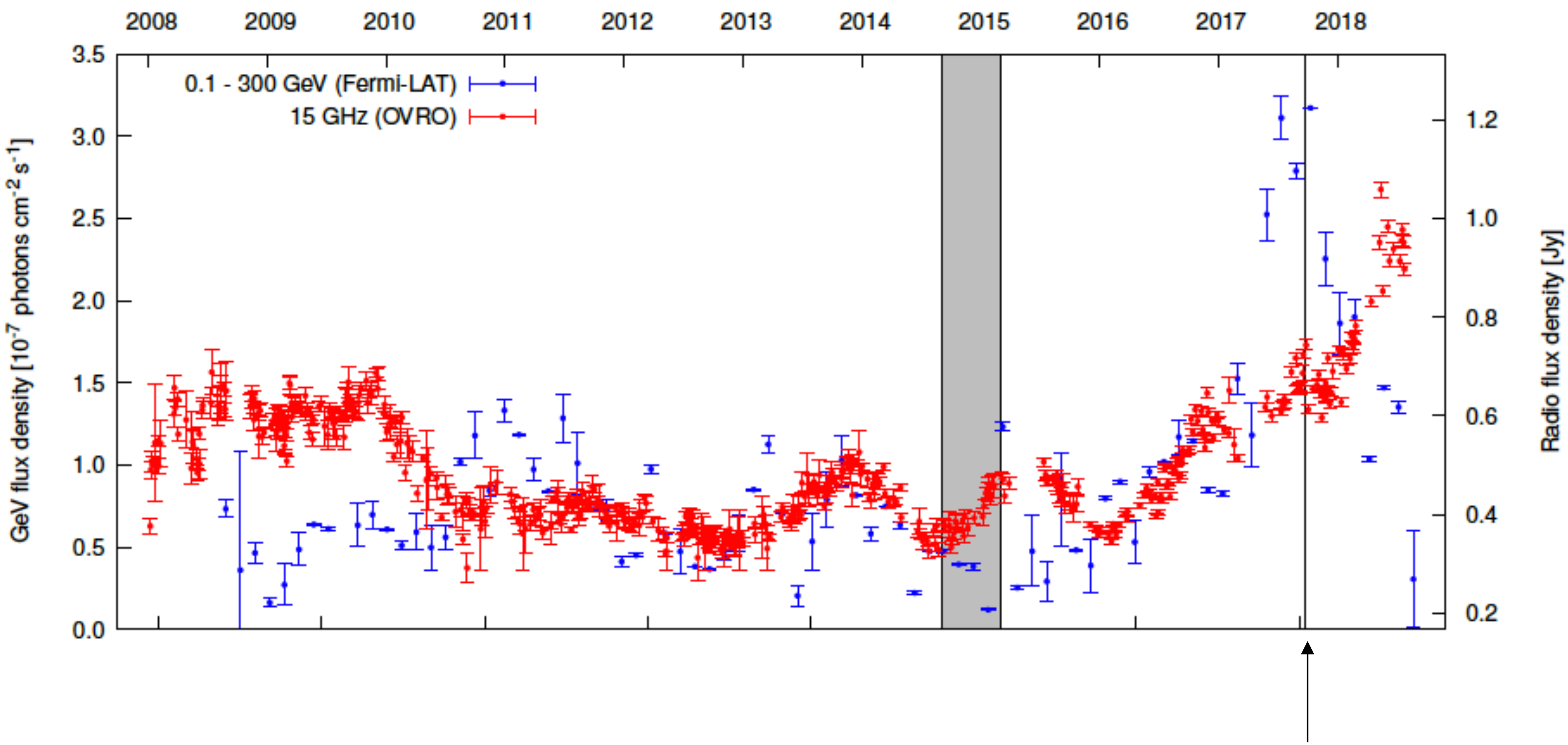
Accepted . Received ; in original form

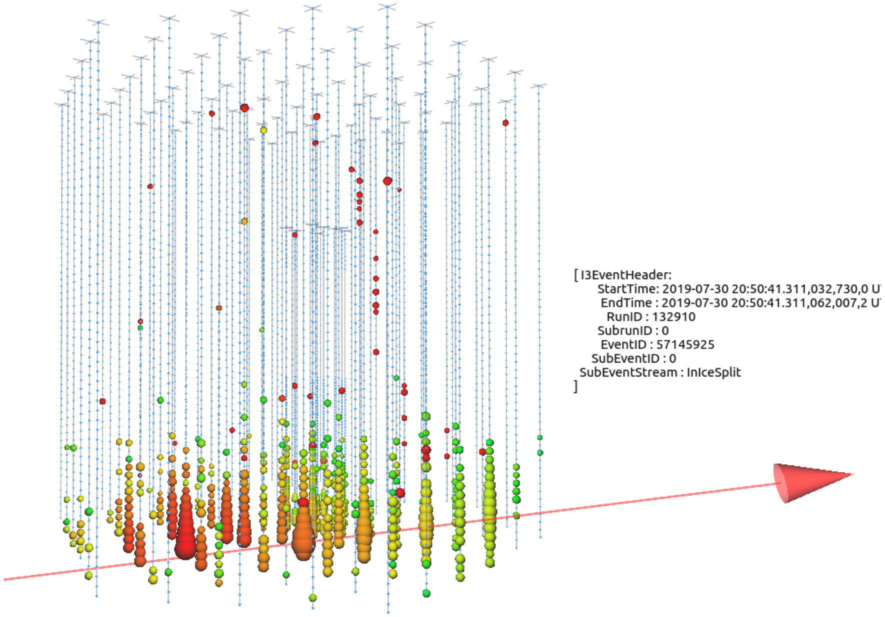
ABSTRACT
We report on the radio brightening of the blazar TXS 0506+056 (at $z = 0.3365$), supporting its identification as source of the high-energy (HE) neutrino IC-170922A by the IceCube Neutrino Observatory. MOJAVE/VLBA data indicate its radio brightness abruptly increasing since January 2016. When decomposing the total radio flux density curve (January 2008 - July 2018) provided by the Owens Valley Radio Observatory into eight Gaussian flares, the peak time of the largest flare overlaps with the HE neutrino detection, while the total flux density exhibits a threefold increase since January 2016. We reveal the radio structure of TXS 0506+056 by analysing VLBI data from the MOJAVE/VLBA Survey. The jet-components maintain quasi-stationary core separations. The structure of the ridge line is indicative of a jet curve at the region $0.5 \div 2$ mas ($2.5 \div 9.9$ pc projected) from the VLBI core. The brightness temperature of the core and the pc-scale radio morphology support a helical jet structure at small inclination angle ($< 8^{\circ}.2$). The jet pointing towards the Earth is key property facilitating multimessenger observations (HE neutrinos, γ- and radio flares). The radio brightening preceding the detection of a HE neutrino is similar to the one reported for the blazar PKS 0723–008 and IceCube event ID5.

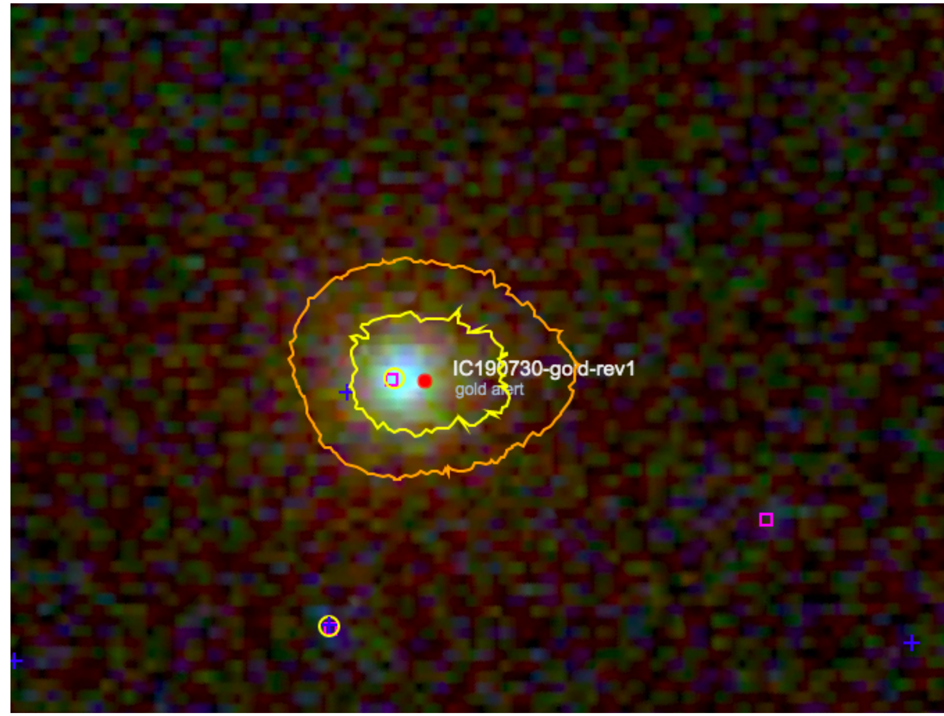
Key words: galaxies: BL Lacertae objects: individual: TXS 0506+056 – physical data and processes: neutrinos –radio continuum: galaxies – techniques: interferometric



2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
0.1 - 300 GeV (Fermi-LAT)
15 GHz (OVRO)
GeV flux density [10^-7 photons cm^-2 s^-1]
Radio flux density [Jy]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.2
1.0
0.8
0.6
0.4
0.2

TXS 0506+056





IC 190730: 300 TeV

- coincident with PKS 1502+106
- galaxy merger

[Previous | Next]

Neutrino candidate source FSRQ PKS 1502+106 at highest flux density at 15 GHz

ATel #12996; *S. Kiehlmann (IoA FORTH, OVRO), T. Hovatta (FINCA), M. Kadler (Univ. WÃ¼rzburg), W. Max-Moerbeck (Univ. de Chile), A. C.S. Readhead (OVRO)*
on ***7 Aug 2019; 12:31 UT***
Credential Certification: Sebastian Kiehlmann (skiehlmann@mail.de)

Subjects: Radio, Neutrinos, AGN, Blazar, Quasar

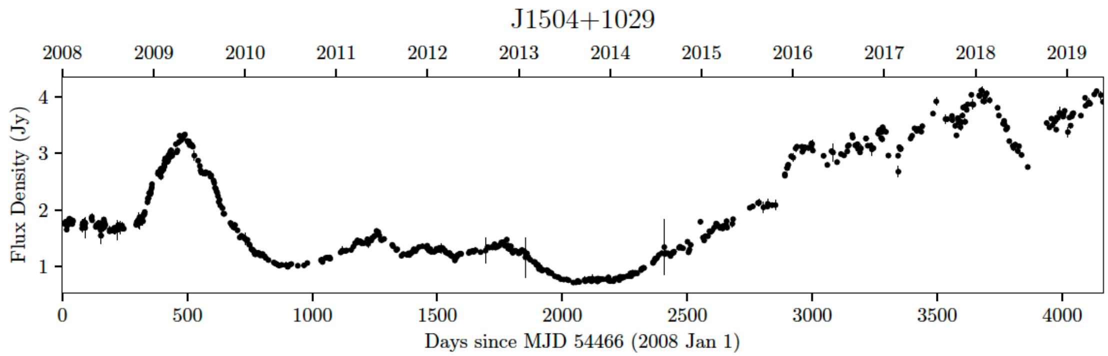
Tweet

On 2019/07/30.86853 UT IceCube detected a high-energy astrophysical neutrino candidate (Atel #12967). The FSRQ PKS 1502+106 is located within the 50% uncertainty region of the event. We report that the flux density at 15 GHz measured with the OVRO 40m Telescope shows a long-term outburst that started in 2014, which is currently reaching an all-time high of about 4 Jy, since the beginning of the OVRO measurements in 2008. A similar 15 GHz long-term outburst was seen in TXS 0506+056 during the neutrino event IceCube-170922A.

Related

12996	Neutrino candidate source FSRQ PKS 1502+106 at highest flux density at 15 GHz
12985	IceCube-190730A: Swift XRT and UVOT Follow-up and prompt BAT Observations
12983	Optical fluxes of candidate neutrino blazar PKS 1502+106
12981	ASKAP observations of blazars possibly associated with neutrino events IC190730A and IC190704A
12974	Optical follow-up of IceCube-190730A with ZTF
12971	IceCube-190730A: MASTER alert observations and analysis
12967	IceCube-190730A an astrophysical neutrino candidate in spatial coincidence with FSRQ PKS 1502+106
12926	VLA observations reveal increasing brightness of 1WHSP J104516.2+275133, a potential source of IC190704A

OVRO Radio Flare



OVRO Montitoring (http://www.astro.caltech.edu/ovroblazars/)

Neutrino candidate source FSRQ PKS 1502+106 at highest flux density at 15 GHz

ATel #12996; *S. Kiehlmann (IoA FORTH, OVRO), T. Hovatta (FINCA), M. Kadler (Univ. WÃ¼rzburg), W. Max-Moerbeck (Univ. de Chile), A. C.S. Readhead (OVRO)*
on 7 Aug 2019; 12:31 UT
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Subjects: Radio, Neutrinos, AGN, Blazar, Quasar

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No evidence of short-term flaring activity in any wavelengths.

Long-term radio flare reported by OVRO, also reported for TXS 0506+056.

the two highest energy IceCube alerts are coincident with radio flares

are blazars the sources of the cosmic neutrinos?

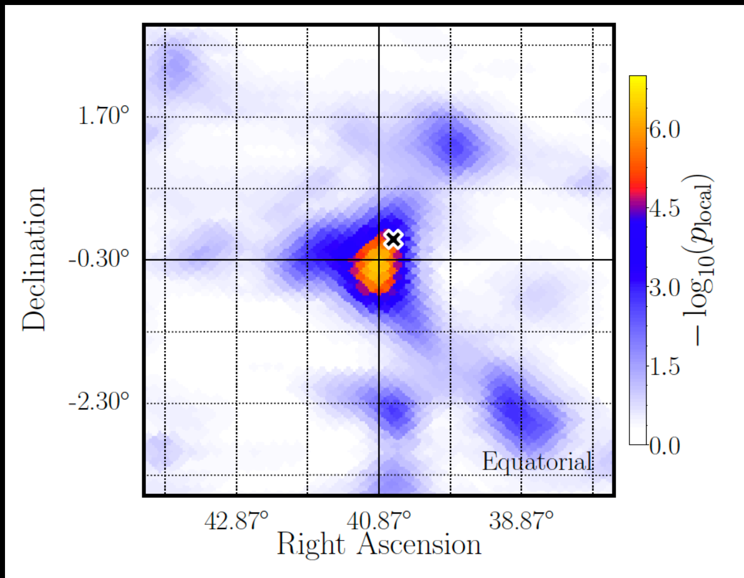
a special class of gamma ray sources that undergo 110-day duration flares like TXS 0506+056 once every 10 years accommodates the observed diffuse flux of high-energy cosmic neutrinos

- selected by redshift evolution ?
- galaxy mergers (VLA observations during 2014 burst) ?

of the highest energy cosmic rays?

measured flux satisfies the energy requirement

arXiv:1812.05654 - arXiv:1811.07439 - arXiv:1811.06356 - arXiv:1807.07942



evidence for M77
(NGC1086)

- agn activity
- merger (with a star-forming region or satellite galaxy)
- nearby!

A&A 567, A125 (2014)
DOI: 10.1051/0004-6361/201423843
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Astronomy & Astrophysics

Molecular line emission in NGC 1068 imaged with ALMA★

I. An AGN-driven outflow in the dense molecular gas

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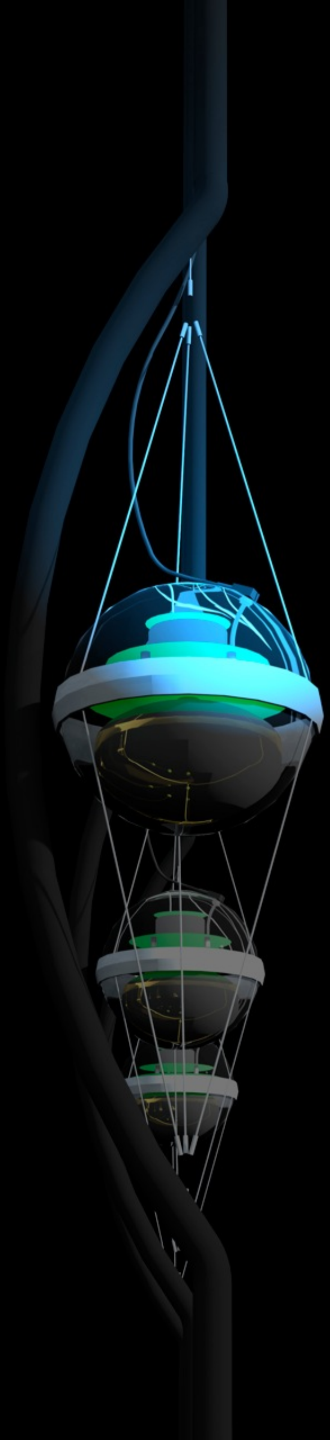
ABSTRACT

Aims. We investigate the fueling and the feedback of star formation and nuclear activity in NGC 1068, a nearby (D = 14 Mpc) Seyfert 2 barred galaxy, by analyzing the distribution and kinematics of the molecular gas in the disk. We aim to understand if and how gas accretion can self-regulate.

Methods. We have used the Atacama Large Millimeter Array (ALMA) to map the emission of a set of dense molecular gas ($n(H_2) \simeq 10^{5-6}$ cm^{-3}) tracers (CO(3–2), CO(6–5), HCN(4–3), HCO$^+$(4–3), and CS(7–6)) and their underlying continuum emission in the central $r \sim 2$ kpc of NGC 1068 with spatial resolutions ~0.3″–0.5″ (~20–35 pc for the assumed distance of D = 14 Mpc).

Results. The sensitivity and spatial resolution of ALMA give an unprecedented detailed view of the distribution and kinematics of the dense molecular gas ($n(H_2) \geq 10^{5-6}$cm^{-3}) in NGC 1068. Molecular line and dust continuum emissions are detected from a $r \sim 200$ pc off-centered circumnuclear disk (CND), from the 2.6 kpc-diameter bar region, and from the $r \sim 1.3$ kpc starburst (SB) ring. Most of the emission in HCO$^+$, HCN, and CS stems from the CND. Molecular line ratios show dramatic order-of-magnitude changes inside the CND that are correlated with the UV/X-ray illumination by the active galactic nucleus (AGN), betraying ongoing feedback. We used the dust continuum fluxes measured by ALMA together with NIR/MIR data to constrain the properties of the putative torus using CLUMPY models and found a torus radius of 20^{+6}_{-10} pc. The Fourier decomposition of the gas velocity field indicates that rotation is perturbed by an inward radial flow in the SB ring and the bar region. However, the gas kinematics from $r \sim 50$ pc out to $r \sim 400$ pc reveal a massive ($M_{\rm mol} \sim 2.7^{+0.9}_{-1.2} \times 10^7$ $M_\odot$) outflow in all molecular tracers. The tight correlation between the ionized gas outflow, the radio jet, and the occurrence of outward motions in the disk suggests that the outflow is AGN driven.

Conclusions. The molecular outflow is likely launched when the ionization cone of the narrow line region sweeps the nuclear disk. The outflow rate estimated in the CND, $dM/dt \sim 63^{+21}_{-37}$ $M_\odot$ yr^{-1}, is an order of magnitude higher than the star formation rate at these radii, confirming that the outflow is AGN driven. The power of the AGN is able to account for the estimated momentum and kinetic luminosity of the outflow. The CND mass load rate of the CND outflow implies a very short gas depletion timescale of ≤1 Myr. The CND gas reservoir is likely replenished on longer timescales by efficient gas inflow from the outer disk.



cosmic neutrinos: four independent observations

→ muon neutrinos through the Earth
→ starting neutrinos: all flavors
→ high energy tau neutrinos
→ a Glashow resonance event

IceCube neutrinos and Fermi photons

the cosmic ray accelerator TXS 0506+056

multimessenger astronomy from radio to PeV neutrinos

- a new class of sources and a new class of telescopes

icecube.wisc.edu

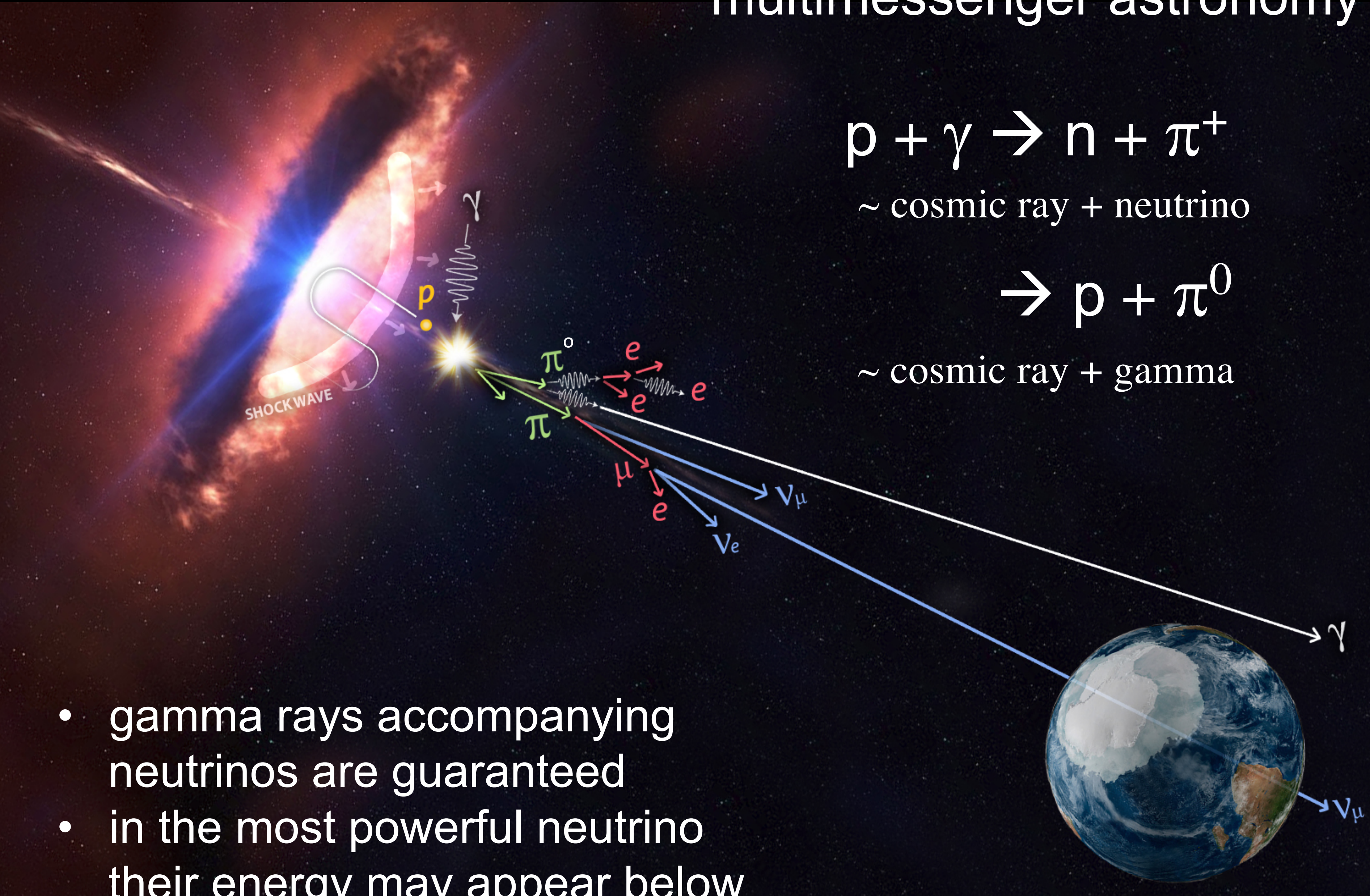
multimessenger astronomy

$$p + \gamma \rightarrow n + \pi^{+}$$

~ cosmic ray + neutrino

$$\rightarrow p + \pi^{0}$$

~ cosmic ray + gamma



- gamma rays accompanying neutrinos are guaranteed
- in the most powerful neutrino their energy may appear below GeV-TeV wavelengths

multimessenger neutrinos: a new class of sources and a new class of telescopes